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ABSTRACT

This course in heating, ventilating, and air conditioning is one of 16 courses in the Energy Technology Series developed for an Energy Conservation-and-Use Technology curriculum. Intended for use in two-year postsecondary technical institutions to prepare technicians for employment, the courses are also useful in industry for updating employees in company-sponsored training programs. Comprised of eight modules, the course is designed to develop an understanding of air conditioning and heating systems and their characteristics, applications, and limitations. It presents the basics of such systems and factors affecting the selection and efficient operation of both commercial and residential heating and air conditioning equipment. Written by a technical expert and approved by industry representatives, each module contains the following elements: introduction, prerequisites, objectives, subject matter, exercises, laboratory materials, laboratory procedures (experiment section for hands-on portion), data tables (included in most basic courses to help students learn to collect or organize data), references, and glossary. Module titles are Basic Refrigeration Cycle, System Types, Refrigeration Equipment, Residential Heating Equipment, Boilers for Heating Applications, Piping, Air Handling Equipment, and Psychrometrics. (YLB)

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HEATING, VENTILATING, AND AIR CONDITIONING

CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT
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PREFACE

ABOUT ENERGY TECHNOLOGY MODULES

The modules were developed by CORD for use in two-year postsecondary technical institutions to prepare technicians for employment and are useful in industry for updating employees in company-sponsored training programs. The principles, techniques, and skills taught in the modules, based on tasks that energy technicians perform, were obtained from a nationwide advisory committee of employers of energy technicians. Each module was written by a technician expert and approved by representatives from industry.

A module contains the following elements:

Introduction, which identifies the topic and often includes a rationale for studying the material.

Prerequisites, which identify the material a student should be familiar with before studying the module.

Objectives, which clearly identify what the student is expected to know for satisfactory module completion. The objectives, stated in terms of action-oriented behaviors, include such action words as operate, measure, calculate, identify, and define, rather than words with many interpretations such as know, understand, learn, and appreciate.

Subject Matter, which presents the background theory and techniques supportive to the objectives of the module. Subject matter is written with the technical student in mind.

Exercises, which provide practical problems to which the student can apply this new knowledge.

Laboratory Materials, which identify the equipment required to complete the laboratory procedure.

Laboratory Procedures, which is the experiment section, or "hands-on" portion, of the module (including step-by-step instruction) designed to reinforce student learning.

Data Tables, which are included in most modules for the first year (or basic) courses to help the student learn how to collect and organize data.

References, which are included as suggestions for supplementary reading/viewing for the student.

Test, which measures the student's achievement of prestated objectives.

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MODULE HC-07 Air-Handling Equipment

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HEATING, VENTILATING, AND AIR CONDITIONING
INTRODUCTION

Energy used for heating and air conditioning represents the largest residential energy expenditure and one of the largest expenditures for commercial and industrial facilities as well.

Thus, an understanding of air conditioning and heating systems and their characteristics, applications, and limitations is essential for those personnel interested in conserving energy and reducing energy expenditures.

This course is designed to develop such an understanding. A complete description of air conditioning and heating systems and the skills necessary for designing, operating, and maintaining them would fill many volumes. The intent of this course is not to develop expertise in these areas, but to present the basics of such systems and factors affecting the selection and efficient operation of both commercial and residental heating and air conditioning equipment.

Many kinds of equipment and systems are in use; new types are constantly being developed, as rising energy costs make more efficient operation necessary. Only common equipment types and systems are discussed here.

One area of new technology that has great promise in the HVAC industry is the application of solar energy to both heating and cooling. While practical solar cooling systems are not yet available, solar energy is currently being used for many heating applications. The use of solar energy in heating and cooling systems is sure to grow. Solar energy is not discussed in this course, but students should note that the hot water used for heating application may be produced by solar collectors.

The Heating, Ventilating, and Air Conditioning course consists of the following modules:

Module HC-01, "Basic Refrigeration Cycle," describes the basic components and operation of a refrigeration system. HC-01 includes the properties of refrigerants and the use of the pressure-enthalpy diagrams in examining the operation of refrigeration systems. The laboratory for HC-01 consists of the operation of a small refrigeration system and plotting the system characteristics on a pressure-enthalpy diagram. Energy flow through the system is stressed.

Module HC-02, "System Types," describes various systems used to deliver heating or cooling to conditioned space. Characteristics and applications of all-air, air-and-water, all-water, and unitary systems are discussed. The principles of operation of heat pumps are included. The laboratory for this module includes the first of four field trips to a commercial air conditioning installation. The purpose of this trip is to examine the central station and become familiar with the system.

Module HC-03, "Refrigeration Equipment," describes the components commonly found in large air conditioning systems and their operation. Topics include reciprocating and centrifugal compressors, metering devices, condensers and cooling towers, evaporators and water chillers, and system accessories and controls. The operation of absorption chillers is also included. The laboratory consists of a second field trip, during which the refrigeration components and system are examined in detail.

Module HC-04, "Residental Heating Equipment," describes electric, gas-fired and oil-fired heating equipment used for residential heating applications. The discussion includes system controls, efficiency, and basic inspection and maintenance procedures. The laboratory consists of performing maintenance and operation procedures on a standard gas-fired residential furnace.

Module HC-05, "Boilers For Heating Applications," describes the construction and operation of boilers for heating application. Topics include the design of various boiler types, with emphasis on the scotch marine boiler that is most commonly used. Other topics are oil and gas burner design, boiler controls, gas trains, and flame safeguard systems. The laboratory for this module is a third field trip, during which students will examine the boiler of a large HVAC installation.

Module HV-06, "Piping," discusses the characteristics of piping in HVAC systems. Topics include types of pipes and valves, resistance to flow in piping systems, and the design and characteristics of piping systems to carry water, refrigerant, and steam. The laboratory consists of soldering and brazing copper pipes.

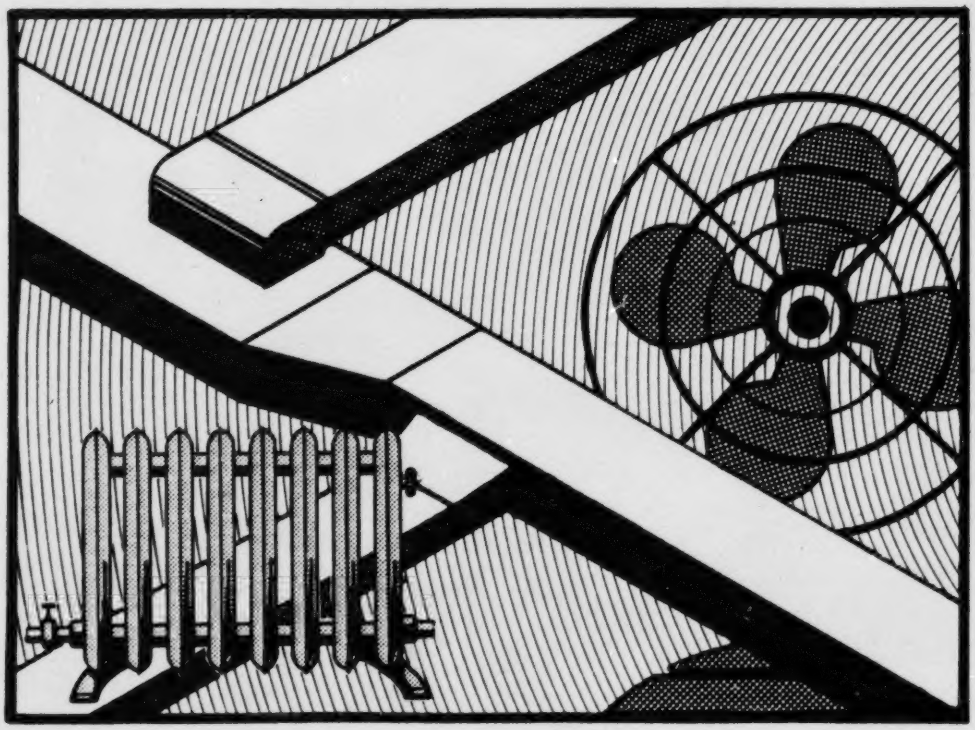
Module HC-07, "Air-Handling Equipment," describes the characteristics and applications of various fan types and ductwork. Additional topics include basic air flow principles, air velocity in ducts, placement and types of grills and registers, and duct configurations of various system types. The laboratory of this module is the last of four field trips, during which the ductwork and air-handling equipment of a large air conditioning system will be examined.

Module HC-08, "Psychrometrics," describes the characteristics of air that are changed by air conditioning and heating processes. The characteristics and uses of the psychrometric chart are described, and the chart is used in problem solving and system design. The laboratory is a pencil and paper exercise using the chart.

ENERGY TECHNOLOGY

CONSERVATION AND USE

HEATING, VENTILATING, AND AIR CONDITIONING



MODULE HC - 01

BASIC REFRIGERATION CYCLE

CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

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CORD

CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

INTRODUCTION

Heat energy always travels from a high temperature region to a lower temperature region, lowering the higher temperature and raising the lower temperature until the two are equal with the system in thermal equilibrium. To lower the temperature of a body or to maintain it at a temperature lower than its environment, heat energy must be removed from the body.

A refrigeration system is a "thermal pump" that creates or maintains a temperature difference by absorbing heat energy from a "cold" substance and releasing it into a "hot" substance.

Refrigeration systems are key elements in food storage, processing, and marketing, in environmental control, and in many industrial processes. In all these systems heat transfer is accomplished by a circulating medium, called a "refrigerant," that absorbs heat from one location through evaporation and releases it at another location through condensation.

This module discusses the basic refrigeration cycle, components and operation of a basic refrigeration system, and common measurements that are performed on such a system. In the laboratory the student will operate a simple refrigeration system, measure system pressures and temperatures, and diagram the operation of the system.

PREREQUISITES

The student should have completed Unified Technical Concepts I, II, and III; Mechanical Devices and Systems; and Electromechanical Devices.

OBJECTIVES

Upon completion of this module the student should be able to:

1. List the four major elements of a refrigeration system and explain the purpose of each. Include how each of the following refrigerant characteristics changes in each component:
   a. Temperature.
   b. Pressure.
   c. Energy content.
   d. State (liquid or gas).
2. Draw and label a diagram of a simple refrigeration system and identify the following parts:
   a. Compressor.
   b. Hot gas line.
   c. Condenser.
   d. Warm liquid line.
   e. Metering device.
   f. Evaporator.
   g. Cold gas pipe.
3. Given a simplified pressure-enthalpy diagram, identify the following:
   a. Subcooled liquid zone.
   b. Superheated vapor zone.
   c. Mixed liquid and vapor zone.
   d. Saturated liquid line.
   e. Saturated vapor line.
   f. Constant pressure line.
   g. Constant enthalpy line.
   h. Constant temperature line.
   i. Constant volume line.

    - j. Constant entropy line.
    - k. Constant quality line.
4. Given a blank pressure-enthalpy chart, draw a diagram of a refrigeration cycle and identify the following:
    - a. Condensation line.
    - b. Evaporation line.
    - c. Expansion line.
    - d. Compression line.
    - e. Subcooling of liquid.
    - f. Superheating of vapor.
5. Explain the purposes of superheating and subcooling.
6. Draw a diagram showing the proper connection of a gauge manifold to a refrigeration system.
7. List in order the proper steps for attaching the gauge manifold to a system and for removing the manifold from the system. Refer to the diagram in Objective 6.
8. Solve refrigeration system problems of the following type:

Given:	Pressure-enthalpy diagram of refrigerant. High-side pressure. Low-side pressure. Compressor discharge temperature. Temperature of warm liquid line. Temperature of suction line.
Find:	Condensation temperature. Evaporation temperature. Net refrigeration effect. Energy of compression. Heat rejection in condenser. Coefficient of performance. Percent of vapor entering evaporator.

9. Given a blank pressure-enthalpy diagram and the appropriate equipment, measure the pressures and temperatures present in an operating refrigeration system and draw the operating cycle of the system on the pressure-enthalpy diagram. Determine the following quantities:
   a. Condensation temperature.
   b. Evaporation temperature.
   c. Net refrigeration effect.
   d. Energy of compression.
   e. Heat rejection in condenser.
   f. Coefficient of performance.

PRINCIPLES OF REFRIGERATION

Figure 1 illustrates the basic principles of all refrigeration systems. The purpose of this system is to reduce the temperature of a volume and the material it contains to a temperature below that of the surroundings.

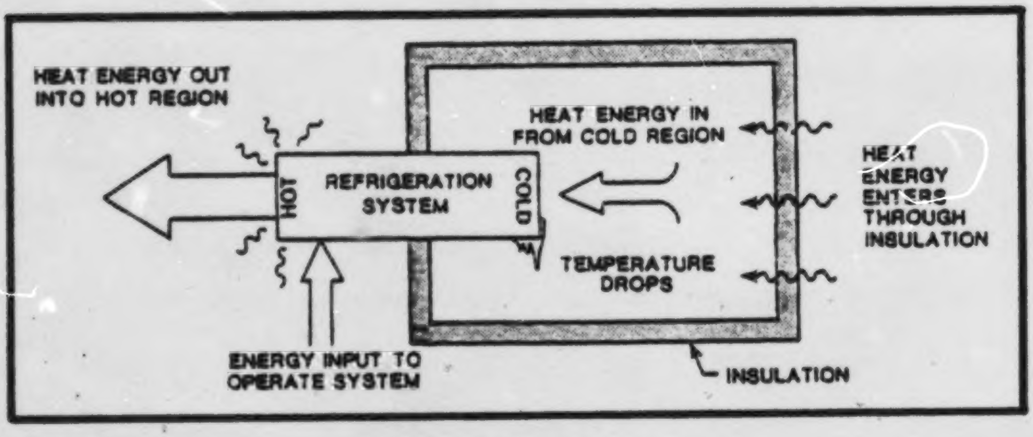

HEAT ENERGY OUT INTO HOT REGION
HEAT ENERGY IN FROM COLD REGION
HOT
REFRIGERATION SYSTEM
COLD
HEAT ENERGY ENTERS THROUGH INSULATION
TEMPERATURE DROPS
ENERGY INPUT TO OPERATE SYSTEM
INSULATION

Figure 1. Principles of Refrigeration.

Heat energy always moves from a region of high temperature to a region of lower temperature. Separating the two regions by insulation reduces heat flow but does not stop it. The refrigeration system absorbs heat energy from the cold region and rejects it into the hotter region, thereby lowering the temperature of the cold region. A heat pump is used to pump the heat energy from the cold region to the hotter one.

To absorb heat energy from its surroundings the cold side of the refrigeration system must be colder than its surroundings. Moreover, the hot side of the refrigeration system must be hotter than its surroundings in order to reject heat. The temperature difference across the system is produced by energy from an external source. In the mechanical refrigeration cycle discussed in this module, input energy is mechanical energy to a compressor. The energy rejected by the system is the total of its operating energy and the heat energy absorbed from the cold region.

Efficient operation of a refrigeration system depends upon insulation of the cold region and transfer of the maximum thermal energy with the minimum operating energy.

BASIC REFRIGERATION COMPONENTS

Figure 2 shows the four basic components of a mechanical refrigeration system. This system transfers heat by circulating a fluid refrigerant through a closed loop. At some points the refrigerant is a liquid, and at others it is a gas (vapor). Heat transfer occurs primarily through change of state of the refrigerant.

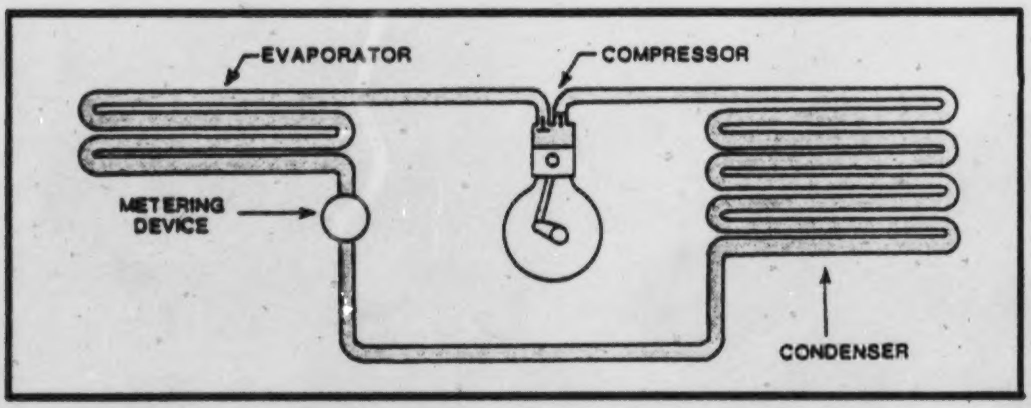


Figure 2. Basic Refrigeration Components.

COMPRESSOR

The compressor is a mechanical device that applies the operating energy to increase the temperature, pressure, and internal energy of the refrigerant in the vapor state. Vapor enters the compressor from the evaporator with a low pressure and low temperature and leaves with a higher pressure and higher temperature. The compressor adds the operating energy to the refrigerant and forces it through the system.

CONDENSER

The condenser rejects heat into the hot region. The hot vapor from the compressor enters the condenser at a temperature above the temperature of the air surrounding the condenser. Heat energy is transferred through the condenser walls, cooling the refrigerant and causing it to condense into liquid. The condenser reduces the temperature of the hot gas to the condensation temperature, removes latent heat at the condensation temperature to change the gas to liquid, and cools the liquid to a temperature below the condensation temperature. The condenser operates at the high-side pressure of the compressor outlet. It reduces the internal energy and temperature of the refrigerant and changes the refrigerant from a gas to a liquid.

METERING DEVICE

Hot liquid refrigerant from the condenser flows through a metering device which restricts the flow of the fluid, producing a pressure drop from the high-side pressure to the low-side pressure. The refrigerant expands as it passes through the metering device; then its temperature drops. The refrigerant leaving the metering device is a mixture of cold liquid and low-pressure vapor. The energy content of the refrigerant does not change as it passes through the valve.

EVAPORATOR

The evaporator absorbs heat energy from the cold region. The refrigerant enters the evaporator at low pressure with a temperature below that of the surroundings. Heat energy is then transferred through the evaporator walls, heating the refrigerant and causing the remaining liquid to boil into vapor. The evaporator has a constant temperature and pressure. Only the energy content and the state of the refrigerant change.

BASIC REFRIGERATION SYSTEM

Figure 3 shows a basic refrigeration system with all major components and refrigerant lines identified. The high-pressure side of the system extends from the outlet of the compressor A to the metering device E. The low-pressure side extends from the metering device back to the inlet of

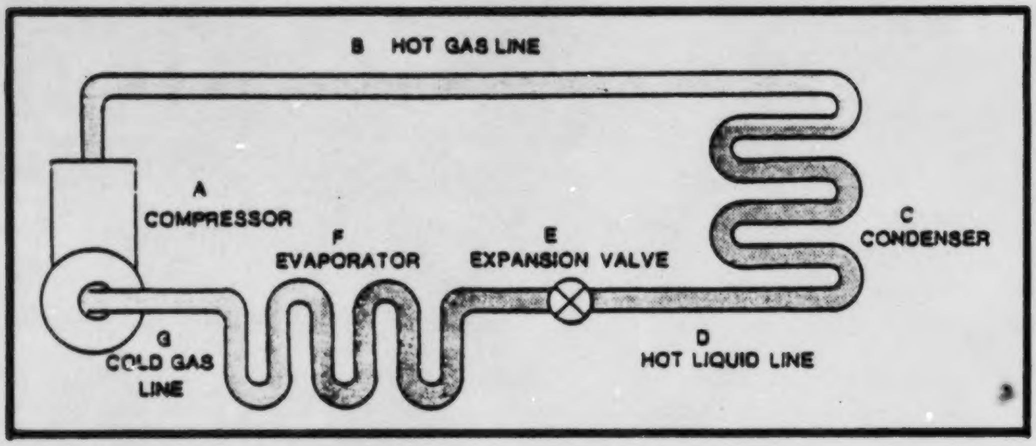


Figure 3. Schematic of a Basic Refrigeration System.

the compressor. The temperature given for each component in the following discussion is the approximate value of the refrigerant in that component in a residential air conditioning system using Refrigerant R-12 with a high-side pressure of 185 psia (pounds per square inch absolute) and a low-side pressure of 40 psia.

Hot vapor (180°F) from the compressor (A) flows through the hot gas line (B) to the condenser (C), (125°F), where it condenses into liquid. The hot liquid refrigerant (85°F) flows through the hot liquid line (D) to the expansion valve (E). After the refrigerant passes through the valve into the evaporator (F), the pressure is the low-side pressure, and the temperature (25°F) is the temperature of evaporation. The cold liquid refrigerant absorbs heat in the evaporator and changes to cold vapor. This vapor (35°F) flows through the cold gas line (G), also called the "suction line," back to the compressor.

PRESSURE-ENTHALPY DIAGRAM

The operating characteristics of any refrigeration system are determined by the refrigerant used. Many refrigerants are available, and the characteristics of each are presented in a diagram called a "pressure-enthalpy diagram" (Figure 4). The vertical axis of the diagram is absolute pressure (psia), and the horizontal axis is enthalpy. Enthalpy is the energy content of the refrigerant in Btu/lb – which is usually stated relative to liquid refrigerant at -40°F. The enthalpy of the refrigerant may change because of a change in temperature (sensible heat) or because of a change in state (latent heat).

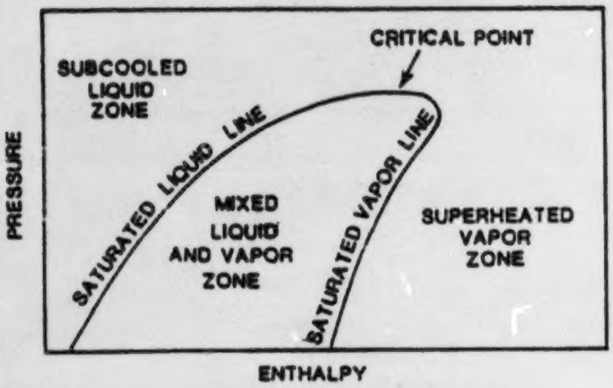

CRITICAL POINT
SUBCOOLED LIQUID ZONE
SATURATED LIQUID LINE
SATURATED VAPOR LINE
MIXED LIQUID AND VAPOR ZONE
SUPERHEATED VAPOR ZONE
PRESSURE
ENTHALPY

Figure 4. Pressure-Enthalpy Diagram.

The pressure-enthalpy diagram is divided into three regions. To the left of the saturated liquid line is the subcooled liquid zone. In this zone the refrigerant is 100% liquid at a pressure and temperature that will not allow the formation of vapor. Vapor can be produced only if the temperature is raised or the pressure is lowered.

To the right of the saturated vapor line is the superheated vapor zone. Superheated vapor has sufficient energy content that no liquid can condense unless the temperature is decreased or the pressure is increased.

Between the two saturated lines is the mixed liquid and vapor zone. In this zone both liquid and vapor refrigerant are present. Within this zone a change in internal energy at a fixed pressure changes the relative amounts of liquid and vapor, but not the temperature.

The critical point is the maximum pressure at which the refrigerant can exist as liquid. Above this pressure the refrigerant is always in the vapor state.

REFRIGERANT PROPERTIES

Each point on the pressure-enthalpy diagram corresponds to a particular set of refrigerant properties. Six properties used in describing refrigeration systems are usually included (Figure 5).

PRESSURE (psia)

The vertical scale is absolute pressure in pounds per square inch. A logarithmic scale is used so the entire useful range of the refrigerant can be included on a chart of reasonable size. Lines of constant pressure (Figure 5a) run horizontally across the chart.

ENTHALPY (Btu/lb)

The horizontal scale is enthalpy (internal energy) in Btu per pound of refrigerant. Absolute enthalpy is of no interest. Only changes in enthalpy are important. The

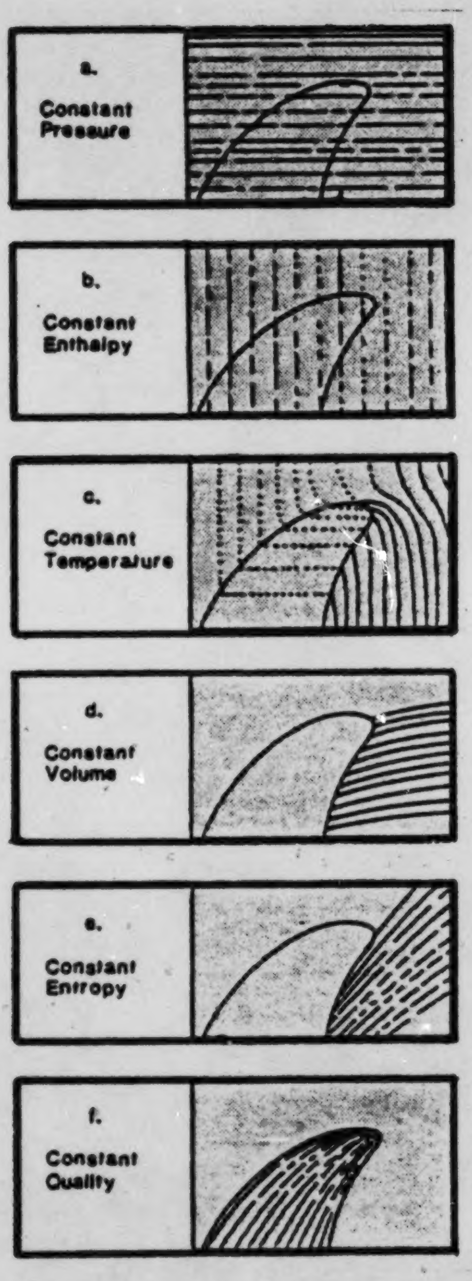

a.
Constant Pressure
b.
Constant Enthalpy
c.
Constant Temperature
d.
Constant Volume
e.
Constant Entropy
f.
Constant Quality

Figure 5. Refrigerant Properties on the Pressure-Enthalpy Diagram.

enthalpy scale is linear, and constant enthalpy lines run vertically (Figure 5b).

TEMPERATURE (°F)

Lines of constant temperature (Figure 5c) run in a vertical direction in the subcooled liquid zone, in a horizontal direction in the mixed zone, and almost vertically in the super-heated vapor zone. On most charts the constant temperature lines are omitted in the first two zones (dotted lines), as they are easily determined from scales along the saturated liquid line and saturated vapor line.

SPECIFIC VOLUME (ft^3lb)

Lines of constant volume (Figure 5d) extend to the right of the saturated vapor line at a slight angle above horizontal. Constant volume lines are of no interest in the other zones and will not be used elsewhere in this module.

ENTROPY (Btu/lb °F)

Entropy is the ratio of heat energy transferred per pound (added to or subtracted from a substance) to the absolute temperature at which this heat flow occurs. This is a mathematical quantity that cannot be measured but can be calculated from measured physical quantities. Entropy is important in compressor operation. Constant entropy lines (Figure 5e) extend to the upper right of the saturated vapor line as they have practical use only in the superheated vapor zone.

PERCENT VAPOR

In the mixed liquid and vapor zone, part of the refrigerant is vapor and part is liquid. Lines of "constant quality" (Figure 5f) extend to the upper right in this zone and are calibrated according to the percent of the refrigerant in the vapor state.

Figure 6 is the complete pressure-enthalpy diagram for refrigerant R-12.

REFRIGERATION CYCLE

Energy flow through a refrigeration system can be examined by drawing a diagram of the refrigeration cycle on the pressure-enthalpy diagram of the refrigerant used in the system. The cycle diagram consists of four lines, each indicating the effect of one of the four major components upon the refrigerant.

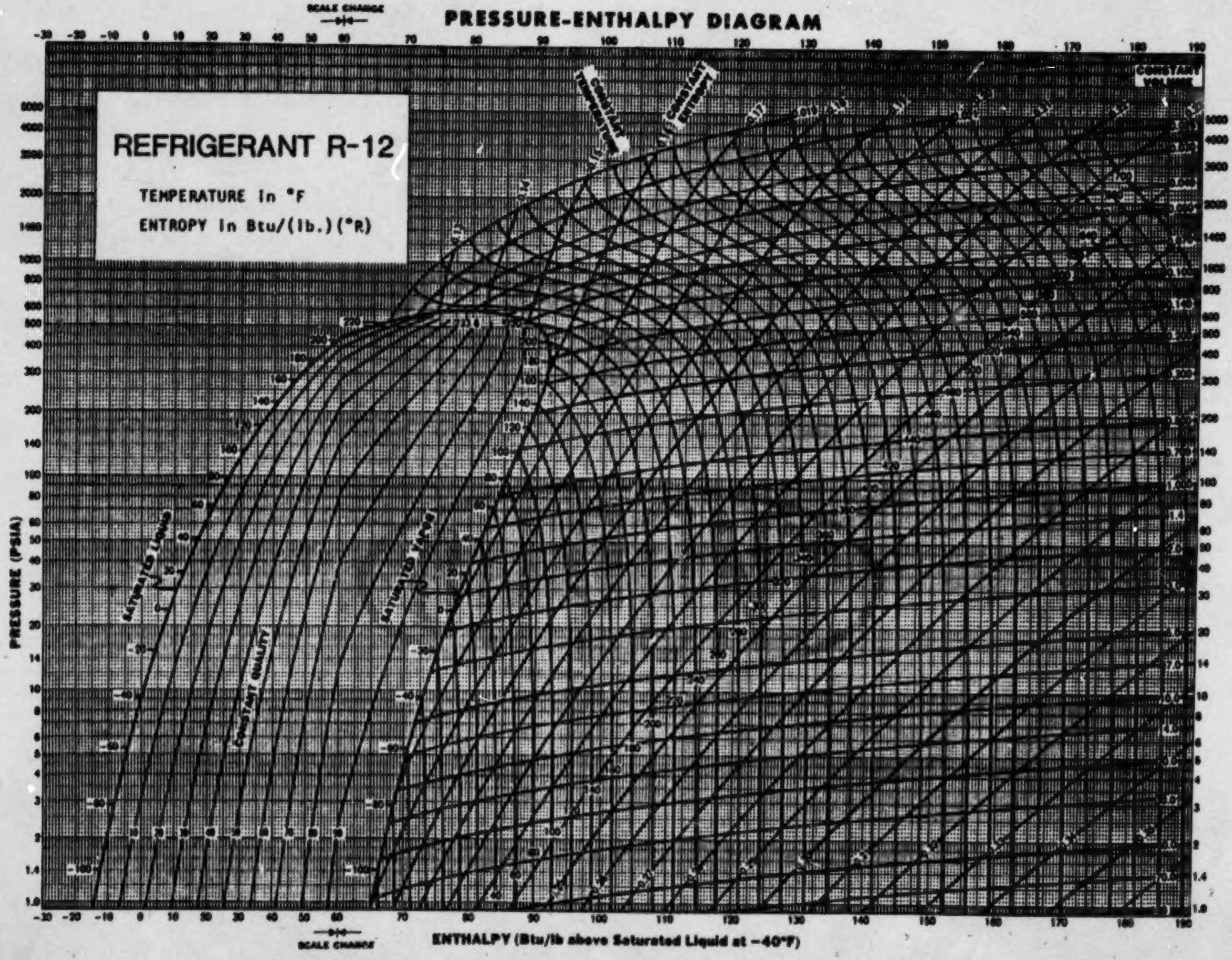


Figure 6. Pressure-Enthalpy Diagram for Refrigerant R-12.

CONDENSATION LINE

Condensation occurs at a constant pressure. The condensation line is a horizontal line (Figure 7a) to the left at the pressure of the condenser. Displacement to the left through the mixed zone along this line indicates decreasing enthalpy as the refrigerant condenses at constant pressure and temperature. The length of this line in the superheated vapor zone indicates heat that must be removed before the vapor reaches saturation and condensation begins. Some of this heat is dissipated through the hot gas line and causes a temperature drop along that line. An extension of the condensation line into the subcooled liquid zone indicates removal of heat from the warm liquid line and a temperature drop along it.

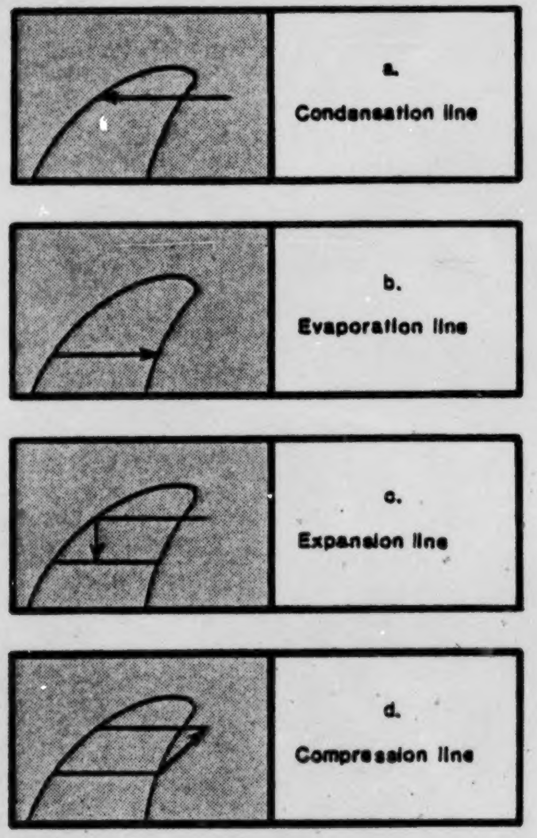


Figure 7. Components of the Refrigeration Cycle.

EVAPORATION LINE

Evaporation also occurs at constant pressure. The evaporation line (Figure 7b) is a horizontal line to the right at the pressure of the evaporator. This line always starts in the mixed zone. Displacement to the right along this line indicates an increase in enthalpy at constant temperature and pressure as the refrigerant evaporates. An extension of this line into the superheated vapor zone indicates absorption of energy and a temperature increase in the cold gas line.

EXPANSION LINE

Expansion occurs with no change in enthalpy. The expansion line (Figure 7c) extends downward from the condensation line to the evaporation line, crossing the saturated liquid line at the temperature of the liquid refrigerant in the warm liquid line. The lower end of this line indicates the percentage of the refrigerant that is vaporized upon expansion.

COMPRESSION LINE

Compression occurs in an ideal compressor at constant entropy. The compression line (Figure 7d) is a line of constant entropy upward from the end of the evaporation line to the end of the condensation line. Vapor pressure, temperature, and enthalpy all increase along this line.

IDEAL SATURATED CYCLE

Figure 8 shows the ideal saturated cycle, illustrating the functions of the four basic components of all refrigeration systems. Line segments AB, BC, CD, and DA respectively represent condensation, expansion, evaporation, and compression.

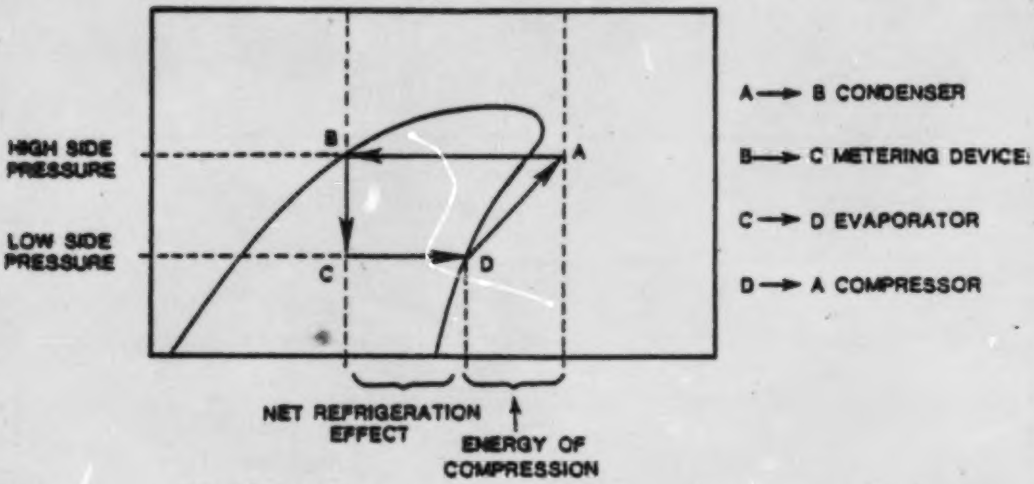

HIGH SIDE PRESSURE
LOW SIDE PRESSURE
B
A
C
D
A → B CONDENSER
B → C METERING DEVICE
C → D EVAPORATOR
D → A COMPRESSOR
NET REFRIGERATION EFFECT
ENERGY OF COMPRESSION

Figure 8. Ideal Saturated Cycle.

The net refrigeration effect (N.R.E.) is the difference in enthalpy between C and D and is the heat (Btu) removed from the evaporator by each pound of refrigerant. The energy of compression is the difference in enthalpy between D and A and is the energy necessary to compress one pound of refrigerant. The sum of these (A to B) is the energy rejected through the condenser by one pound of refrigerant.

The coefficient of performance (C.O.P.) is defined as "the ratio of net refrigeration effect to energy of compression." It is numerically equal to the heat energy in Btu's removed from the cold region for each Btu of energy used in compression.

ACTUAL OPERATING CYCLE

Figure 9 shows the actual operating cycle of a typical refrigeration system. This cycle differs from the ideal cycle in several details, the most important of which are the subcooling of the liquid in the warm liquid line and the superheating of the vapor in the suction line.

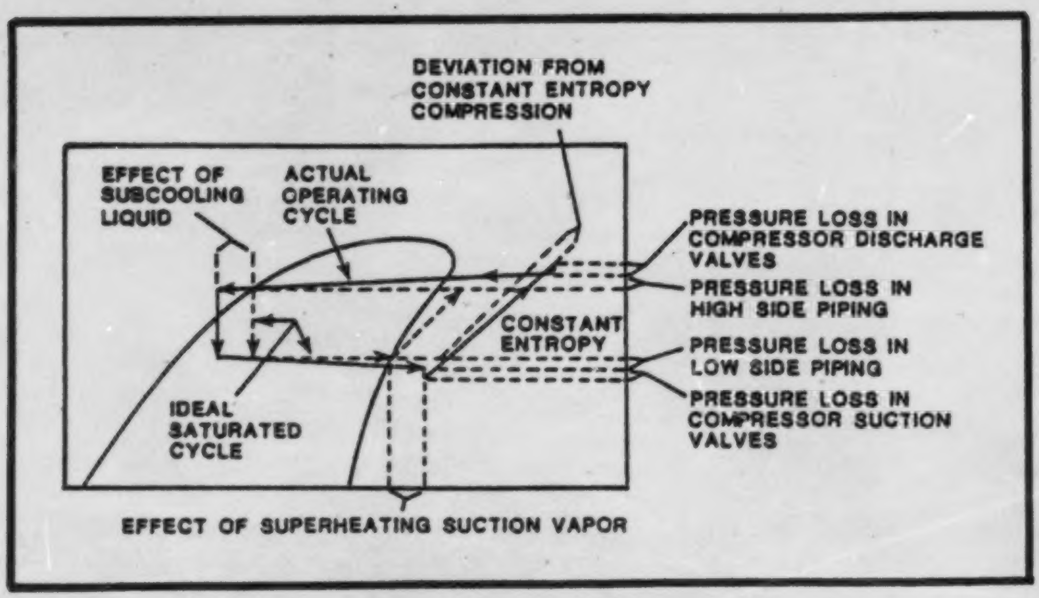

DEVIATION FROM CONSTANT ENTROPY COMPRESSION
EFFECT OF SUBCOOLING LIQUID
ACTUAL OPERATING CYCLE
PRESSURE LOSS IN COMPRESSOR DISCHARGE VALVES
PRESSURE LOSS IN HIGH SIDE PIPING
CONSTANT ENTROPY
PRESSURE LOSS IN LOW SIDE PIPING
PRESSURE LOSS IN COMPRESSOR SUCTION VALVES
IDEAL SATURATED CYCLE
EFFECT OF SUPERHEATING SUCTION VAPOR

Figure 9. Actual Operating Cycle.

Subcooling removes additional energy from the hot (125°F) liquid refrigerant before it reaches the metering device. This action lowers its temperature and results in more liquid refrigerant moving through the metering device, increasing the net refrigeration effect.

Superheating adds energy to the cold (25°F) gas before it enters the compressor. Some superheating is necessary in all systems to assure that only gas enters the compressor. Liquid refrigerant can damage the compressor.

REFRIGERATION SYSTEM ANALYSIS

The performance of a refrigeration system can be evaluated by measuring system pressures and temperatures and drawing a simplified operating cycle of the system on the pressure-enthalpy diagram.

This process, which is illustrated in Example A, will be used in the laboratory.

EXAMPLE A: SYSTEM ANALYSIS.

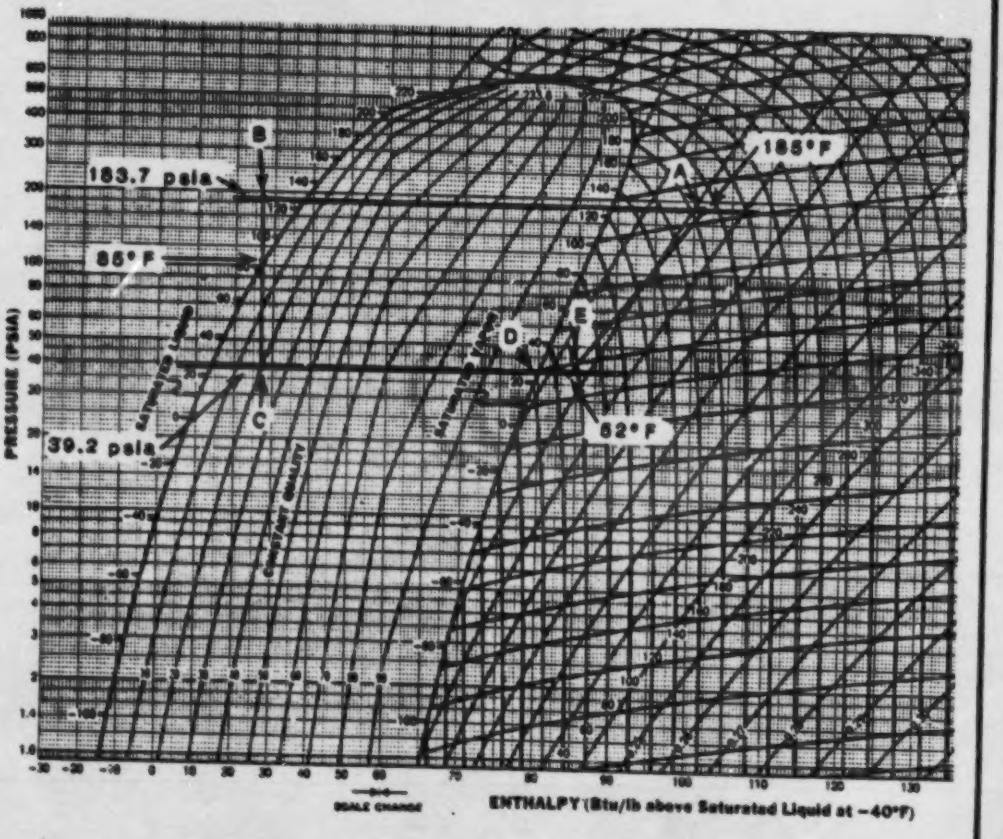
Given: The following quantities were measured for an air conditioner using R-12:

High-side pressure = 169 psig.
Low-side pressure = 24.5 psig.
Compressor discharge temperature = 185°F.
Temperature of warm liquid line = 85°F.
Temperature of suction line = 52°F.

Example A. Continued.

Find:
- a. Condensation temperature.
- b. Evaporation temperature.
- c. Net refrigeration effect.
- d. Energy of compression.
- e. Heat rejection in condenser.
- f. Percent of vapor entering evaporator.
- g. Coefficient of performance.

Solution: Draw the operating cycle by performing the following steps:



Example A. Continued.

1. Convert the measured gauge pressures to atmospheric pressure by adding 14.7 psi.

   Low-side pressure = 24.5 psig + 14.7 psi
   = 39.2 psia.

   High-side pressure = 169 psig + 14.7 psi
   = 183.7 psia.

2. Draw the compression line at high-side pressure of 183.7 psia.
3. Draw the evaporation line at low-side pressure of 39.2 psia.
4. Draw expansion line vertically, downward from condensation line to the evaporation line so that it passes through the intersection of the saturated liquid line of the chart and the temperature of the warm liquid line (85°F).
5. Locate the point where the right end of the expansion line intersects the temperature of the suction line (52°F) (compressor intake temperature).
6. Locate the point where the right end of the compression line intersects the temperature of the hot gas line (185°F) (compressor discharge temperature).
7. Draw the compression line by connecting the points located in Steps 5 and 6.
8. Label points A, B, C, D, E. This completes the diagram.
9. The following information can be determined from the graph located at the end of Example A.
   a. The condensation temperature of the refrigerant in the condenser is the temperature at which the condensation line crosses the saturated liquid and saturated vapor lines: 125°F.

Example A. Continued.

b. The temperature of the refrigerant in the evaporator is the temperature at which the evaporation line crosses the saturated liquid and saturated vapor lines: 25°F.

c. The net refrigeration effect is the difference in enthalpy between points C and D:

80 Btu/lb - 27 Btu/lb = 53 Btu/lb.

d. The energy of compression is the difference in enthalpy between points D and A:

101 Btu/lb - 84 Btu/lb = 17 Btu/lb.

e. Heat rejection in the condenser is the difference in enthalpy between points A and B.

101 Btu/lb - 27 Btu/lb = 74 Btu/lb.

f. The refrigerant at point C is 20% vapor.

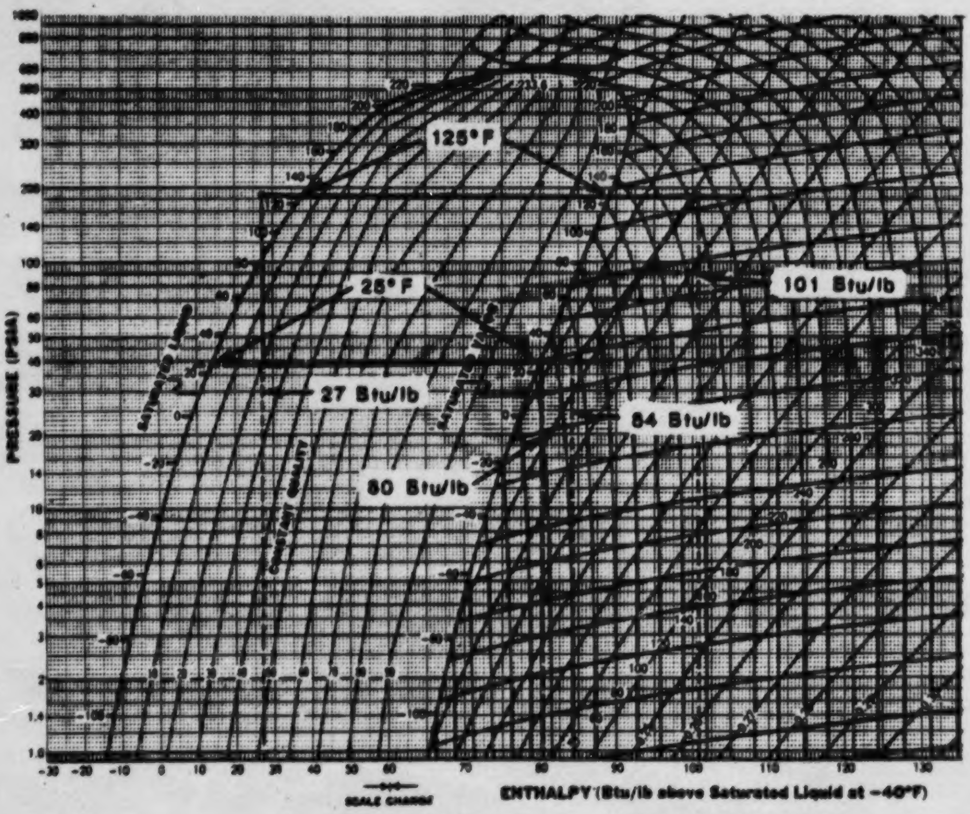
g. $$\text{Coefficient of performance} = \frac{\text{Net refrigeration effect}}{\text{Energy of compression}}$$

$$\text{C.O.P.} = \frac{53\ \text{Btu/lb}}{17\ \text{Btu/lb}}$$

$$\text{C.O.P.} = 3.12.$$

Note that in this system the hot vapor is superheated by 27°F. Better insulation of the cold gas line would reduce the temperature of the compressor and improve system efficiency.

Example A. Continued.



Greater efficiency could also be achieved by greater subcooling of the refrigerant in the hot liquid line.

BASIC REFRIGERATION MEASUREMENTS

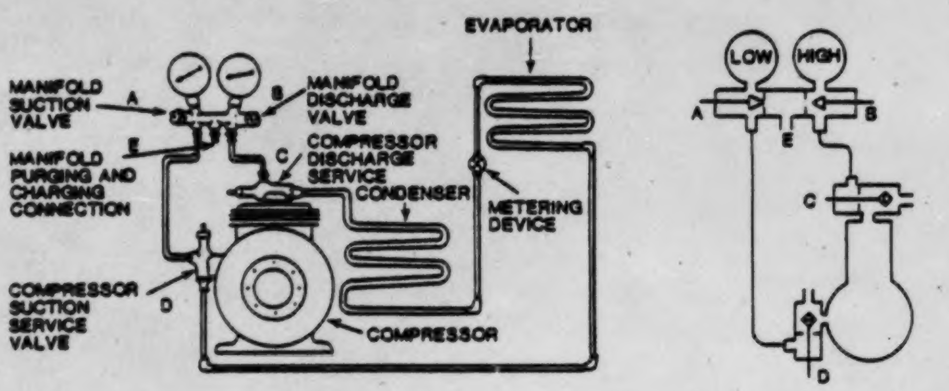
Obtaining the data necessary to draw the refrigeration cycle of an operating system requires measurements of system pressures and temperatures.

GAUGE MANIFOLD

The high-side and low-side pressures are measured with a device called a "gauge manifold" (shown connected to a system in Figure 10). The right gauge is a high-pressure gauge calibrated in pounds per square inch above atmospheric pressure (psig). The left gauge is a compound gauge reading pressures above atmospheric in psig and pressures below atmosphere in inches of mercury. Any measurements made with these guages must be converted to absolute pressure before use on a pressure-enthalpy diagram.

Figure 10b shows the construction of the manifold. Valves A and B are used to connect the two end ports to the center port. They do not disconnect the gauge from the refrigeration system.

Figure 10b also shows the refrigeration service valves (C and D). These valves are located on the compressor and provide access to measure high-side and low-side pressures. They are back-seated (full counterclockwise) when the refrigeration system is in operation. Turning the valves all the way "in" (full clockwise) blocks refrigeration flow.


EVAPORATOR
MANIFOLD SUCTION VALVE
A
B
MANIFOLD DISCHARGE VALVE
E
MANIFOLD PURGING AND CHARGING CONNECTION
C
COMPRESSOR DISCHARGE SERVICE
CONDENSER
METERING DEVICE
COMPRESSOR SUCTION SERVICE VALVE
D
COMPRESSOR
LOW
HIGH
A
B
E
C
D

a. Conventional System with a Gauge Manifold Installed

b. Schematic of Gauge Manifold on System

Figure 10. System and Schematic with Gauge Manifold.

USE OF THE GAUGE MANIFOLD

The following steps are used in connecting the manifold to the system to avoid contaminating the refrigerant with air:

1. Remove valve stem covers.
2. Check valves C and D to be sure they are fully back seated. Refer to Figure 10.
3. Remove covers from valve service ports (C and D).
4. Connect the low pressure gauge to D and the high-pressure gauge to C.
5. Close valves A and B. Leave port E open.

6. Open valve A slightly.
7. Open valve D slightly until gas escapes from port E. Allow hose to be purged until all air is exhausted.
8. Close valve A.
9. Open valve B slightly.
10. Open valve C slightly until gas escapes from port E. Allow hose to be purged until all air is exhausted.
11. Close valve B.

The gauges now read the high-side and low-side pressures. The system can be started and monitored during operation. Additional refrigerant can be added to the system by attaching the refrigerant cylinder to port E, purging the hose, and opening valve A to allow the cylinder to exhaust into the suction side of the compressor. A cylinder should never be connected to the high-pressure side of the compressor.

The following steps are used in removing the gauge manifold from the system to avoid loosing the refrigerant in the high-pressure gauge line:

1. Plug port E but do not seal plug tightly.
2. Open valve A slightly to purge the volume between the gauges.
3. Seal plug.
4. Back-seat valve C (full counterclockwise).
5. With the compressor operating, open valve A.
6. Crack valve B slightly to allow high-pressure refrigerant to flow into suction line. Flow should be slow enough that all refrigerant is vaporized to avoid compressor damage.
7. When both gauges indicate the same pressure, back-seat valve D.

8. Loosen plug or connection and allow gauge pressure to drop to atmospheric.
9. Remove manifold.
10. Replace covers on valve service ports and valve stem caps.

TEMPERATURE MEASUREMENTS

The temperature of the refrigerant in the hot gas line, the hot liquid line, and the suction line can be determined with an electronic contact thermometer. The sensors should be installed on the gas lines as near the compressor as possible and on the hot liquid line just before the metering device. The surface of the pipe should be cleaned with steel wool to remove paint or corrosion. The temperature sensor should be taped onto the pipe and wrapped with insulation.

The temperatures of the condenser and evaporator can be measured in the same way. Accurate temperatures of condensation and evaporation can also be determined from pressure measurements. Most gauges have scales that indicate the evaporation and condensation temperatures for the two most common refigerants, R-12 and R-22.

EXERCISES

1. Explain, with the use of a diagram, the principle of refrigeration.
2. In Example A the net refrigeration effect is 53 Btu/lb and the energy of compression is 17 Btu/lb for a total of 70 Btu/lb. The heat rejection in the condenser is 74 Btu/lb. What is the source of the additional 4 Btu/lb?
3. List the steps for detaching a gauge manifold from a refrigeration system.
4. Identify the processes in the refrigeration cycle that occur at constant...
   a. temperature.
   b. entropy.
   c. enthalpy.
   d. pressure.
5. Draw and label a schematic diagram of a simple refrigeration system, showing all major components and connecting pipes. Give the approximate temperature of the refrigerant in each component. For those in which temperatures change, give approximate upper and lower temperatures.
6. Given the following data on a refrigeration system:
   High-side pressure: 140 psia.
   Low-side pressure: 35 psia.
   Compressor discharge temperature: 145°F.
   Temperature of warm liquid line: 100°F.
   Temperature of suction line: 30°F.
   Pressure-enthalpy diagram for R-12 (following page).

Find: Condensation temperature: ________

Evaporation temperature: ________

Net refrigeration effect: ________

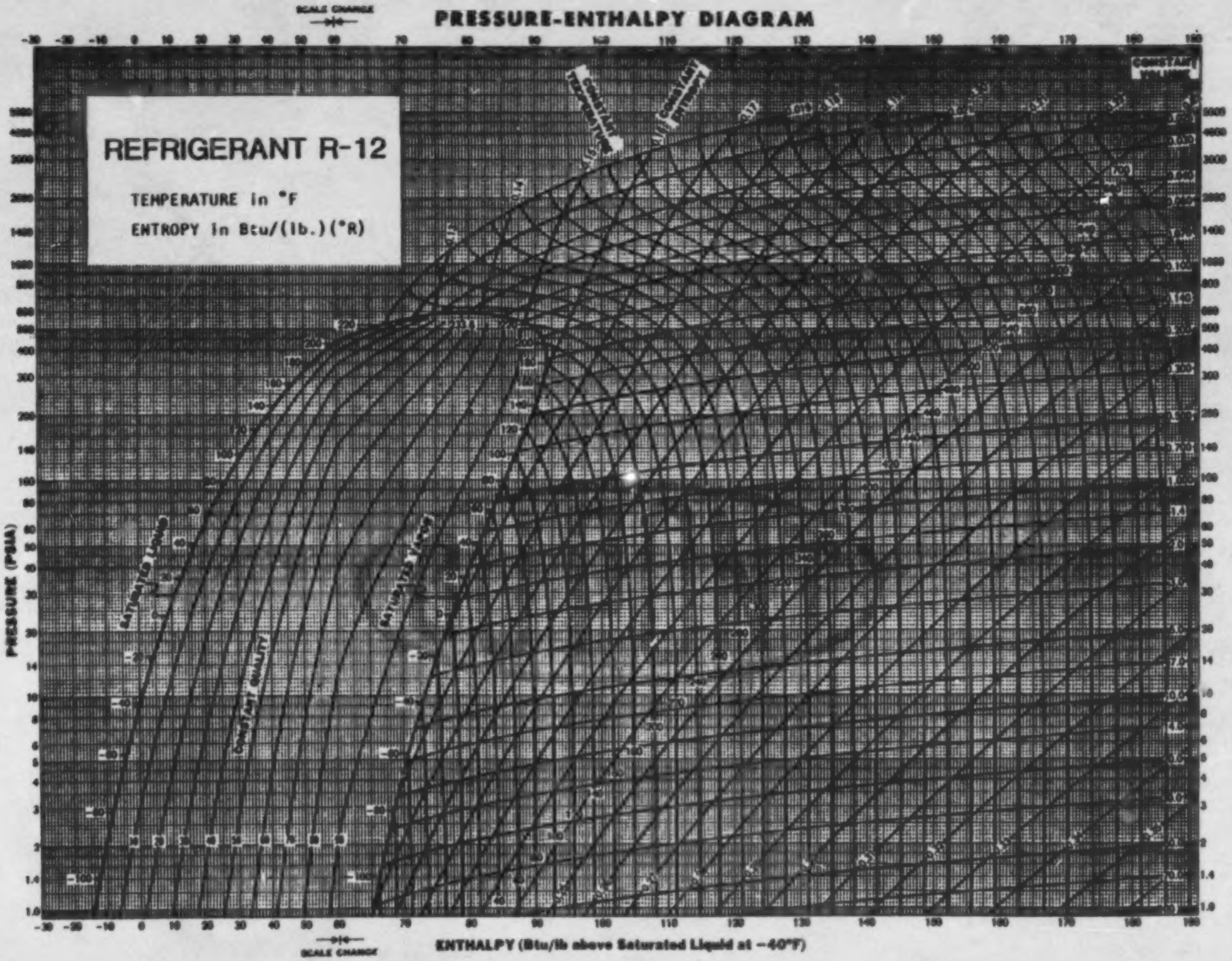
Energy of compression: ________

Heat rejection in condenser: ________

Coefficient of performance: ________

Percent vapor entering evaporator: ________

7. What is the C.O.P. of the above system if the liquid is subcooled to 60°F?


PRESSURE-ENTHALPY DIAGRAM
SCALE CHANGE
REFRIGERANT R-12
TEMPERATURE in °F
ENTROPY in Btu/(lb.)(°R)
CONSTANT TEMPERATURE
CONSTANT ENTROPY
CONSTANT VOLUME
SATURATED LIQUID
SATURATED VAPOR
CONSTANT QUALITY
PRESSURE (PSIA)
ENTHALPY (Btu/lb above Saturated Liquid at −40°F)
-30 -20 -10 0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190
1.0 1.4 2 3 4 5 6 8 10 14 20 30 40 50 60 80 100 140 200 300 400 500 600 800 1000 1400 2000 3000 4000 5000

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LABORATORY MATERIALS

Refrigeration system with R-12 refrigerant.
Gauge manifold.
Electronic contact thermometer with 3 sensors.
Insulating tape.
Wrenches.
Mercury thermometer.

LABORATORY PROCEDURES

1. Attach the temperature sensors to the hot gas line, the warm liquid line, and the suction line, as described in the text.
2. Connect the gauge manifold to the system, as described in the text.
3. Operate the system until it has reached a steady state condition (no temperatures changing).
4. Measure and record the following data in the Data Table:
   a. High-side pressure.
   b. Low-side pressure.
   c. Compressor discharge temperature.
   d. Temperature of warm liquid line.
   e. Temperature of suction line.
5. Use the mercury thermometer to measure the temperature of the air entering and leaving the evaporator and condenser. Record the values in the Data Table.
6. Remove one of the electronic thermometer sensors and use it to measure the evaporator and condenser temperatures. Record the values in the Data Table.
7. Remove the gauge manifold, as described in the text.

8. Use the data taken in Step 4 and Example A to plot the refrigeration cycle on the pressure-enthalpy chart in the Data Table.
9. Use the refrigeration cycle diagram to complete the Data Table.
10. Write a short paragraph explaining the relationships of the following temperatures:
    a. Refrigerant in condenser.
    b. Condenser.
    c. Air into condenser.
    d. Air out of condenser.
11. Repeat Step 10 for the evaporator.
12. Sketch the system and include all measured refrigerant temperatures.

DATA TABLES

DATA TABLE

MEASURED DATA

High-side pressure = _______ psig = _______ psia.

Low-side pressure = _______ psig = _______ psia.

Compressor discharge temperature = _______°F.

Temperature of warm liquid line = _______°F.

Temperature of suction line = _______°F.

Temperature of air entering condenser = _______°F.

Temperature of air leaving condenser = _______°F.

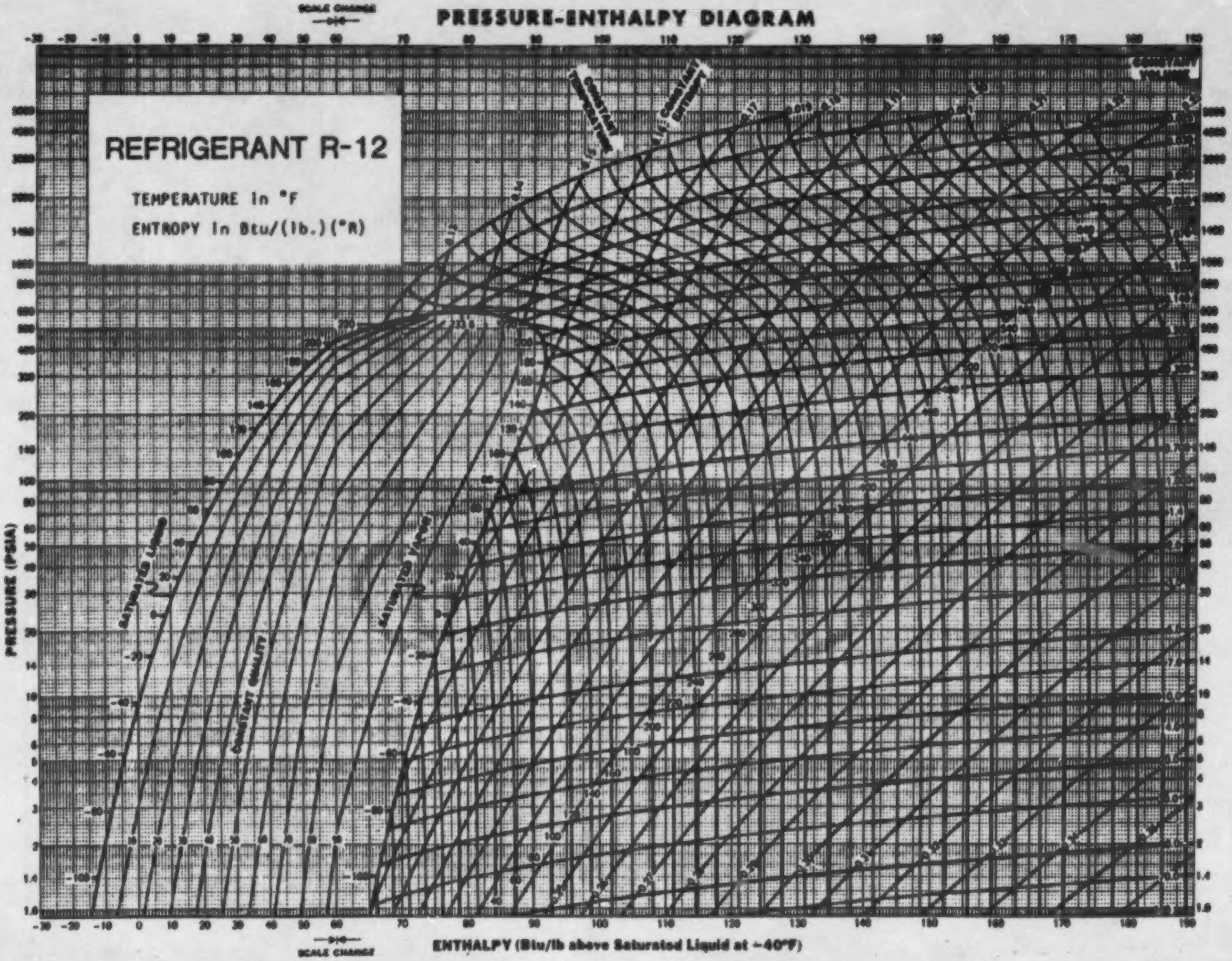
Temperature of air entering evaporator = _______°F.

Temperature of air leaving evaporator = _______ °F.

Temperature of evaporator = _______ °F.

Temperature of condenser = _______°F.

Data Table. Continued.



Data Table. Continued.

FROM REFRIGERATION CYCLE DIAGRAM:

Temperature of condensing refrigerant = _______ °F.

Temperature of evaporating refrigerant = _______ °F.

Net refrigeration effect = _______ Btu/lb.

Energy of compression = _______ Btu/lb.

Energy rejected in condenser = _______ Btu/lb.

Energy gained through superheating = ________ Btu/lb.

Energy released through subcooling = ________ Btu/lb.

Coefficient of performance = _______ .

Percent of vapor refrigerant entering evaporator = _______ %.

Relationships of condenser temperatures:

Relationship of evaporator temperatures:

Data Table. Continued.

SKETCH OF SYSTEM:

REFERENCES

Althouse, Andrew D.; Turnquist, Carl H.; and Bracciano, Alfred. Modern Refrigeration and Air Conditioning. Homewood, IL: The Goodheart and Wilcox Co., Inc., 1968.

The Pressure-Enthalpy Diagram. Special Chemical Division, Allied Chemical International, 40 Rector St., New York, NY 10006.

TEST

Please circle the appropriate answer.

1. The condenser of a refrigeration system ...
   a. operates at a constant temperature.
   b. operates at a constant pressure.
   c. adds heat energy to the refrigerant.
   d. Both a and b are correct.
   e. Both b and c are correct.
   f. Both a and c are correct.

2. The metering device of a refrigeration system ...
   a. reduces the temperature of refrigerant.
   b. reduces the pressure of refrigerant.
   c. reduces the enthalpy of refrigerant.
   d. Both a and b are correct.
   e. All of the above are correct.

3. On a pressure-enthalpy diagram of a refrigeration cycle, the condenser line is directed ...
   a. horizontally to the right.
   b. vertically downward.
   c. vertically upward.
   d. horizontally to the left.
   e. None of the above are correct.

4. On a pressure-enthalpy diagram, lines of constant temperature are ...
   a. vertical in the subcooled liquid zone.
   b. horizontal in the mixed zone.
   c. slightly curved, but almost vertical in the superheated vapor zone.
   d. All of the above are correct.
   e. None of the above are correct.

5. The suction line ...
   a. carries hot liquid refrigerant to the metering device.
   b. has a temperature slightly below the condenser temperature.
   c. has a pressure slightly above the evaporator pressure.
   d. carries cool, low-pressure gas away from the condenser.
   e. None of the above are correct.

6. The enthalpy of the refrigerant ...
   a. is not changed by the metering device.
   b. is increased in both the compressor and evaporator.
   c. is decreased in the condenser.
   d. All of the above are correct.
   e. Only a and b are correct.
   f. Only b and c are correct.

7. Execssive superheating of the gas in the suction line ...
   a. increases the inlet pressure of the compressor.
   b. extends the evaporation line into the subcooled liquid zone of the pressure-enthalpy diagram.
   c. increases compressor operating temperature.
   d. All of the above are correct.
   e. Only a and c are correct.

8. Constant pressure line of a pressure-enthalpy diagram are ...
   a. vertical everywhere.
   b. Horizontal everywhere.
   c. vertical in the subcooled liquid zone and the superheated vapor zone, and slanted upward to the right in the mixed zone.

   d. vertical in the subcooled liquid zone and mixed zone, and slanted upward to the right in the superheated vapor zone.
   e. None of the above are correct.

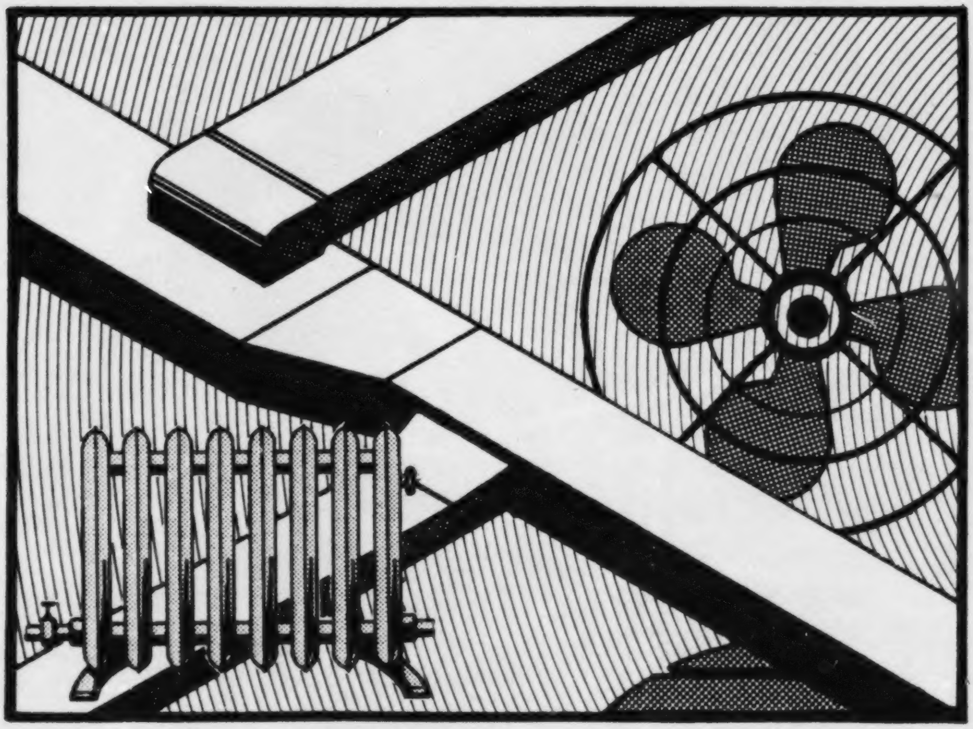
9. Which of the following temperatures are the correct approximate values for a small refrigeration system similar to the one used in the laboratory of this module?
   a. Condenser: 85°F
   b. Suction line: 135°F
   c. Evaporator: 25°F
   d. Hot gas line: 185°F
   e. Only a and c are correct.
   f. Only c and d are correct.

10. Which of the following statements are true concerning the pressures in a refrigeration system?
   a. the evaporator, suction line and compressor inlet have approximately the same pressure.
   b. the condenser, hot gas line, and compressor outlet have approximately the same pressure.
   c. the high side pressure is about 150 psi.
   d. the low side pressure is about atmospheric pressure.
   e. All of the above are true.
   f. All of the above except b are true.
   g. All of the above except c are true.
   h. All of the above except d are true.
   i. Only a and b are true.

ENERGY TECHNOLOGY

CONSERVATION AND USE

HEATING, VENTILATING, AND AIR CONDITIONING



MODULE HC - 02

SYSTEM TYPES

CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

INTRODUCTION

Many configurations are possible for heating, ventilating, and air conditioning systems. System size ranges from window units to the complex systems of large office buildings, hospitals, and airport terminals. Each of the larger systems is unique; each is designed to serve the specific need of the structure of which it is a part. There is so much diversity that the classification of systems into specific types is often difficult.

The American Society of Heating, Refrigerating, and Air Conditioning Engineers has established the following four system categories to include all air conditioning systems:

- All-air systems.
- Air-and-water systems.
- All-water systems.
- Unitary and room air conditioners.

This module describes the characteristics, advantages, disadvantages, and applications of each of these systems. The laboratory exercise consists of a field trip on which students will observe the components and operation of a large central air conditioning system.

PREREQUISITES

The student should have completed Module HC-01, "The Basic Refrigeration Cycle."

OBJECTIVES

Upon completion of this module, the student should be able to:

1. Identify the four major categories of air conditioning systems and describe how the cooling effect is delivered to the conditioned space by each.
2. Draw and label a schematic diagram of the central air handling equipment of a single-zone, all-air system, showing the proper arrangement of the following elements:
    a. Return fan.
    b. Exhaust damper.
    c. Outside air damper.
    d. Filter.
    e. Preheat coil.
    f. Cooling coil.
    g. Heating coil.
    h. Supply fan.
3. State the primary advantage of a single-zone system for most applications.
4. Draw and label diagrams of two types of induction reheat units.
5. State the major advantage and the major disadvantage of a reheat system with low-temperature-air and no-return duct.
6. State three major advantages of a variable-air-volume (VAV) system.
7. Draw and label a diagram of a dual-duct system.
8. Draw and label a diagram of a multi-zone system.
9. Describe the primary difference in the dual-duct system and the multi-zone system and explain why one is chosen over the other in practical applications.

10. State two advantages and two disadvantages of air and water systems as compared to all-air systems.
11. Draw and label the components of a fan coil unit used with a four-pipe all-water system.
12. State one advantage and two disadvantages of all-water systems as compared to all-air and air-and-water systems.
13. Describe the construction characteristics of the following unitary air-conditioning systems:
    a. Single-package units.
    b. Split systems.
    c. Through-the-wall systems.
    d. Room air conditioners.
14. Draw and label diagrams, showing the components of a heat-pump system and the direction of refrigerant flow for the following:
    a. Cooling.
    b. Heating.
15. On a field trip observe the central plant of a large all-air or air-and-water air conditioning system. Draw a schematic diagram of the air handling equipment in the central plant and describe the air-and-water delivery system.

SYSTEM CATEGORIES

Heating and air conditioning systems are classified according to the method used to deliver the heating and cooling effect to the conditioned space. There are four major system types.

ALL-AIR SYSTEMS

In all-air systems heating and cooling is accomplished by the treatment of air in a central plant and the distribution of that air to the conditioned space through a system of ducts. The name does not mean that water is not used as a heat exchange medium in the system. Virtually all of these systems employ water chillers and water-cooled fan coils, but the chilled water is confined to the central plant. Heating may be accomplished by steam or hot water coils or by electrical heating.

AIR-AND-WATER SYSTEMS

Air-and-water systems deliver both air and water to the conditioned space from the central plant. These systems incorporate a duct system to handle heated or cooled air and a piping system to circulate hot or cold water. The water flows through coils in the conditioned space to provide part or all of the heating and cooling.

ALL-WATER SYSTEMS

All-water systems deliver the heating or cooling effect to the conditioned space exclusively through the circulation of hot or cold water. Air within the conditioned space is forced across the water coils by fans.

UNITARY SYSTEMS

Large air conditioning systems are unique systems assembled from individual components. Unitary systems are small air conditioning and heating systems that are composed of one or two factory assembled packages, referred to as "units," that contain the entire system, with the exception of ductwork for air delivery. Unitary air conditioning systems include room air conditioners, residential systems, and heat pumps.

ALL-AIR SYSTEMS

SINGLE-ZONE SYSTEMS

The single-zone system continuously delivers a constant volume of air to the conditioned space. The air is heated or cooled – as required – in the central system. One possible configuration for the central equipment is shown in Figure 1.

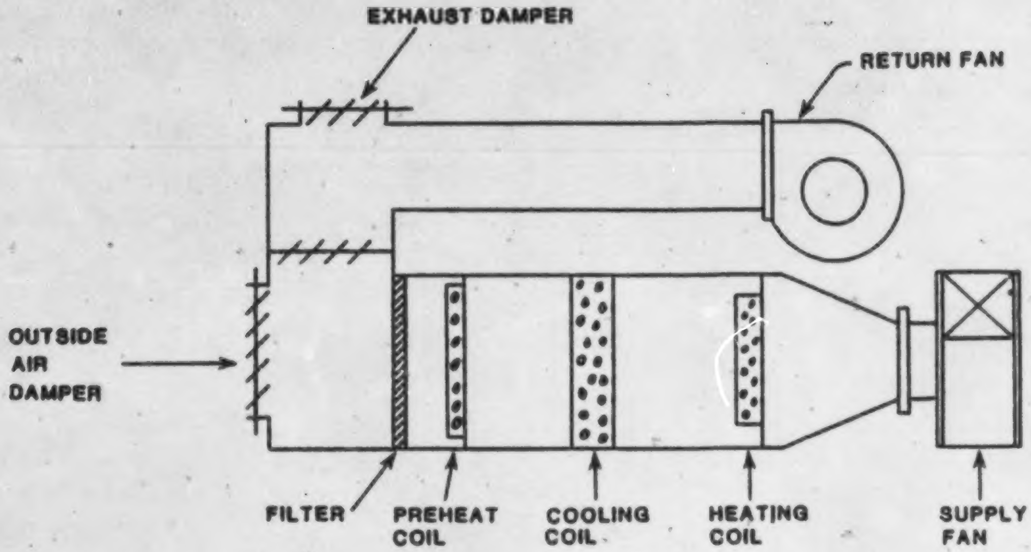

EXHAUST DAMPER
RETURN FAN
OUTSIDE AIR DAMPER
FILTER
PREHEAT COIL
COOLING COIL
HEATING COIL
SUPPLY FAN

Figure 1. Central Equipment of Single-Zone System.

The return air fan brings air from the conditioned space to the central system. Some of this air may be exhausted, and outside air is added for ventilation. The air is filtered, is sent through a series of coils that heat or cool the air, and is forced into the supply duct by the supply fan.

During the cooling operation the cooling coil carries cold water from the chiller of the refrigeration system. During the heating operation the heating coil carries hot water or steam from the boiler. Water remains in the cooling coil but does not flow. If the outside air temperature is low enough, this water could freeze and damage the coil. In such cases a preheat coil can be installed before the cooling coil. Humidifiers, dehumidifiers, and air washes can also be included in the system.

The fans of this system circulate air continuously, whether or not heating or cooling is required. A thermostatic control element, located in the conditioned space or the return air duct, controls the flow of chilled water to the cooling coil or hot water or steam to the heating coils in order to maintain the proper air temperature.

Single-zone systems are effective for heating and cooling of single large spaces, but they cannot be used when different areas of the load have needs that vary independently. Large buildings, for example, require heating of outer areas during the winter, but they require cooling of core areas year-round to remove heat from lights, machinery, and people. A single-zone system cannot meet these needs.

REHEAT SYSTEMS

The reheat system shown in Figure 2 is a modification of the single-zone system. Its purpose is to permit zone control of heating and cooling for areas of unequal loading. The central cooling system is similar to the single-zone system. It provides air temperature to offset the maximum cooling load of the space. If the temperature of the outside air is low enough, the refrigeration equipment is shut off and outside air is used for cooling.

Heating is provided by a separate reheat unit in each zone served. Reheating can be accomplished by (1) hot water or steam coils located within the equipment room in the ducts leading to individual zones, (2) electrical duct heaters located elsewhere in the ductwork, or (3) terminal reheat units located in the conditioned space. If hot water terminal reheat units are used, the system is classified as an "air-and-water reheat system."

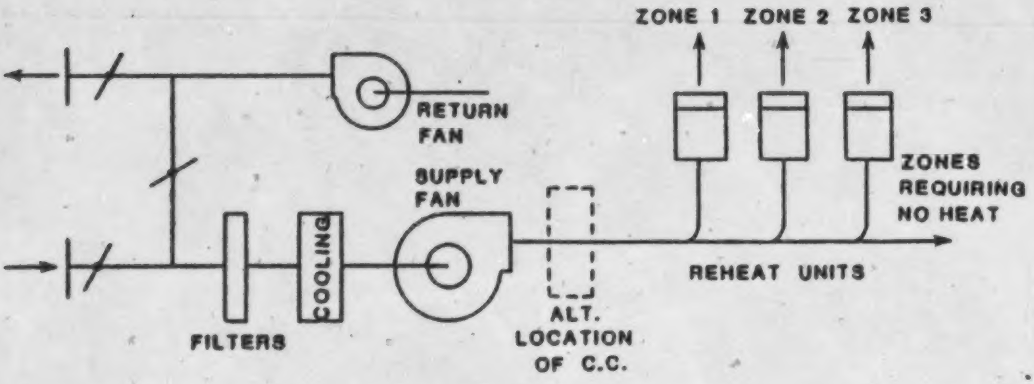


Figure 2. Typical Arrangement of Components for a Reheat System.

The name "reheat" and the equipment arrangement in this system imply the possibility of refrigerating air in the central system and then heating the same air for some zones. This can – and does – occur, but it is not a usual characteristic of system operation. In the summer, when all zones require cooling, little or no heat is supplied. In winter, cold outside air is used for cooling, and the necessary heat is supplied when and where it is needed by the reheat units.

Reheat systems are commonly found in hospitals, laboratories, schools, office buildings, and in other large structures that have different heating and cooling requirements for different zones. They are particularly suited to applications in which some zones require heating while others require cooling, and for areas where humidity control is required.

VARIABLE-VOLUME SYSTEMS

All the systems discussed thus far deliver a constant air flow to the conditioned space. Temperature control is accomplished by controlling the temperature of the air introduced. Variable-air-volume (VAV) systems provide temperature control by controlling both the temperature of the air introduced and the air flow rate. Such a system is shown in Figure 3.

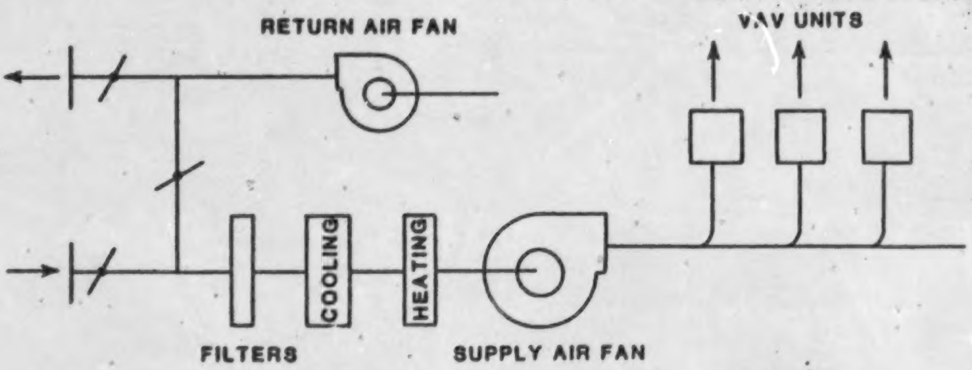


Figure 3. Variable-Air-Volume (VAV) System.

Until recently, variable-volume systems were not recommended for applications with load variations of more than 20% for two reasons. First, throttling conventional outlets down to less than 60% of their design air flow results in loss of control of room air flow and produces drafts. Second, the use of mechanical dampers produces objectionable noise.

Improved throttling devices and aerodynamically designed outlets now allow variable-volume outlets to reduce air flow to 10% of maximum. Figure 4 shows such an outlet with an optional reheat coil installed. Most heating is accomplished in the central system, but reheat units may be installed in zones requiring additional heat.

Variable-volume systems are used in office buildings, schools, apartments, and hospitals. They are best suited for applications in which all zones require either heating or cooling at the same time but have an individual control for each zone. For such applications, variable-volume systems often offer lower initial cost, lower operating cost, and simplicity of control. Operating costs are generally lower for variable-volume systems than for other systems that provide separate room controls. Compared to constant-volume systems, a savings of as much as 35% of the energy cost is possible.

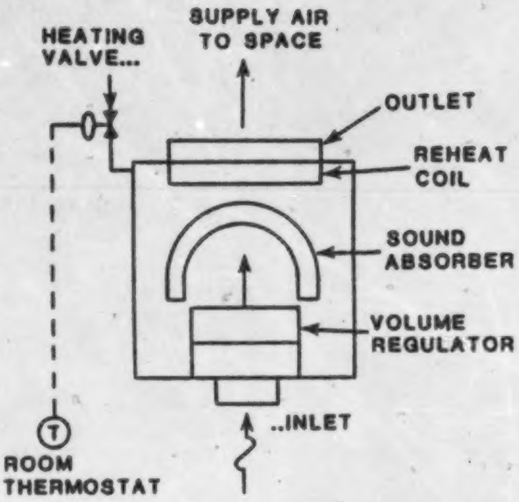
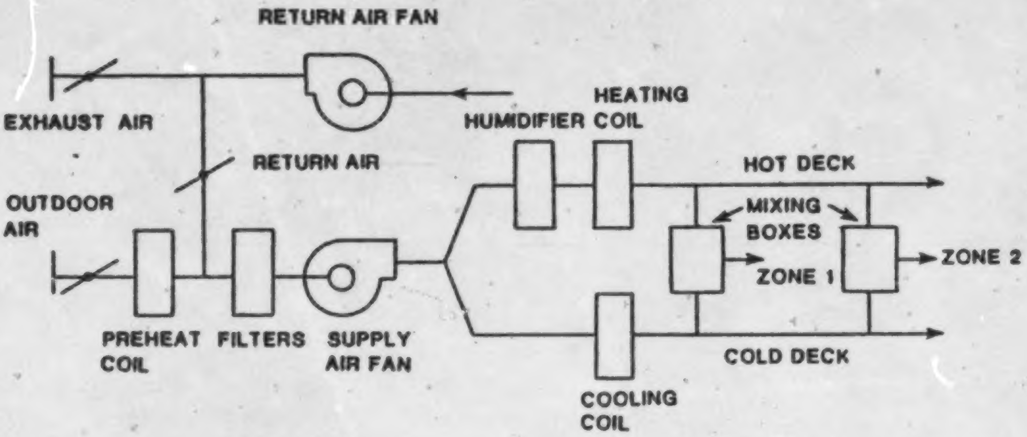


Figure 4. Variable-Air Volume Control Unit.

DUAL DUCT SYSTEMS

The dual-duct system shown in Figure 5 has two separate air delivery systems. During the summer the hot deck carries air at a temperature of about 5°F higher than the temperature of the return air. In winter the hot air temperature is set progressively higher as the outdoor temperature drops. The temperature of the air in the cold deck is maintained at 50 to 55°F. Outdoor air provides a source of hot air in the summer and cold air in the winter. Both hot and cold air are continuously available at each outlet during system operation. The temperature of an individual space is controlled by a thermostat which operates dampers to mix the warm air and cool air in the proper proportions.



RETURN AIR FAN
EXHAUST AIR
HEATING COIL
HUMIDIFIER
RETURN AIR
HOT DECK
OUTDOOR AIR
MIXING BOXES
ZONE 1
ZONE 2
PREHEAT COIL
FILTERS
SUPPLY AIR FAN
COLD DECK
COOLING COIL

Figure 5. Dual-Duct System.

Dual-duct systems are popular in office buildings, hotels, hospitals, and large laboratories because they provide the greatest comfort. Advantages also include prompt and opposite temperature response as required and ease of operation. Starting and stopping the refrigeration machine and boiler are the only normally required adjustments for extreme changes in outdoor temperature. Disadvantages are higher initial cost, greater space requirements for ducts, and possible reduction in energy efficiency since both hot and cold air are continuously supplied to the conditioned space.

MULTI-ZONE SYSTEMS

The central plant of the multi-zone system (Figure 6) is similar to the dual-duct system, and the two systems function in much the same way. The essential difference is the point at which the hot and cold air streams are mixed. In the multi-zone system, all air mixing is done in the central plant, and a separate air duct carries the air to each individual zone.

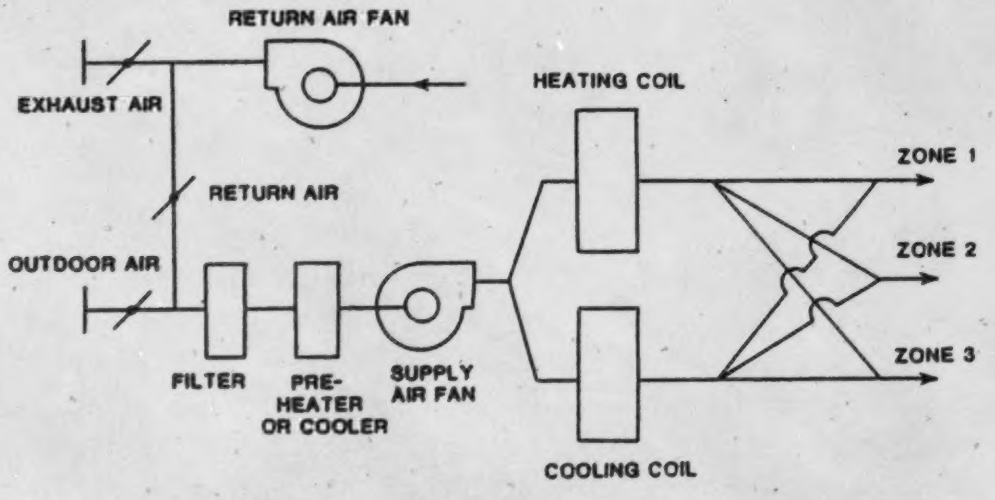

RETURN AIR FAN
EXHAUST AIR
HEATING COIL
ZONE 1
RETURN AIR
ZONE 2
OUTDOOR AIR
ZONE 3
FILTER
PRE-HEATER OR COOLER
SUPPLY AIR FAN
COOLING COIL

Figure 6. Multi-Zone System.

Figure 7 shows the components of the central station of a multi-zone system. In the coil section, the air splits. Part of it flows through the hot deck and part through the cold deck. The hot deck and hot water coils are much smaller than the cold deck and coils because the temperature difference between the hot coil and the air is greater than that between the cold coil and the air. The actual coils installed depend upon the anticipated heating and cooling loads.

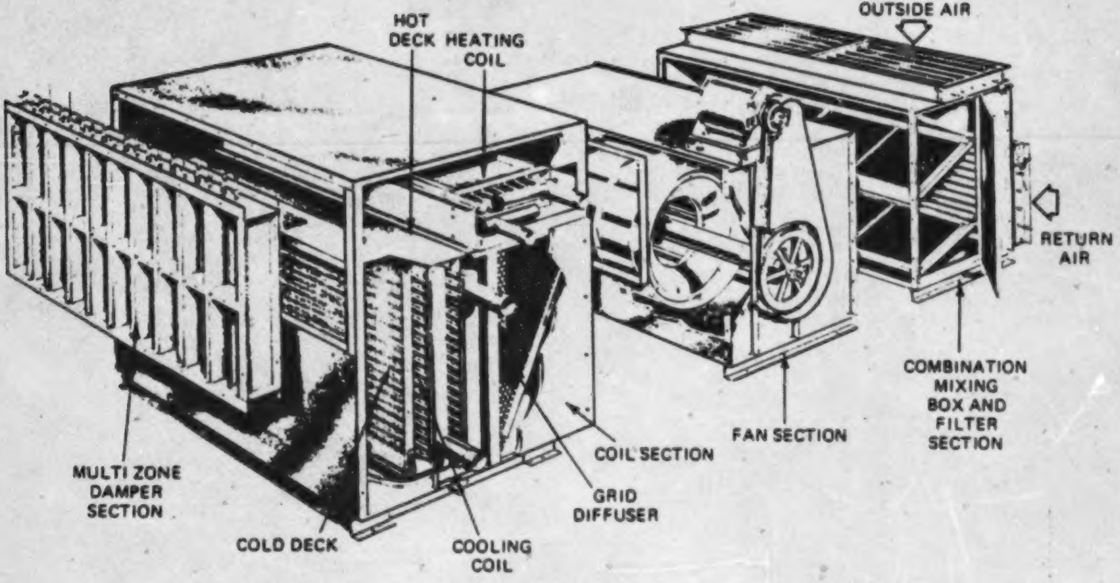

HOT DECK
HEATING COIL
OUTSIDE AIR
RETURN AIR
COMBINATION MIXING BOX AND FILTER SECTION
FAN SECTION
COIL SECTION
GRID DIFFUSER
COOLING COIL
COLD DECK
MULTI ZONE DAMPER SECTION

Figure 7. Multi-Zone Central Station Air Handler.

The individual air ducts for the separate zones (not shown) are attached to the damper section. Hot air flows through the upper half of the damper, and cold air flows through the lower half. The positions of the dampers are controlled by the temperature controllers in the individual zones and result in the proper air temperature for each zone.

Dual-duct systems are used when a large number of small zones, such as individual offices or hospital rooms, require individual control. The multi-zone system offers comparable performance for a relatively small number of larger zones — such as several large, open office areas — with lower initial cost and reduced space requirements.

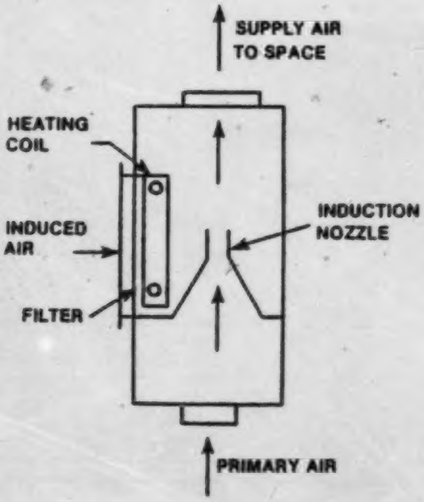
AIR-AND-WATER SYSTEMS

In all-air systems, heating and cooling is accomplished entirely by conditioned air supplied by the central plant. In air-and-water systems, both air and water are distributed to the conditioned space.

In air-and-water reheat systems, the central equipment is similar to that of the single-zone system and provides all cooling. Heating may be accomplished with heating coils in the central system and supplemented by reheat units, or it may be supplied entirely by the reheat units.

Figure 8 shows an induction reheat unit commonly used with such systems and installed under windows in office buildings to provide heating and cooling while offsetting downdrafts in winter. The primary air from the central-supply system flows upward through an induction nozzle, which "induces" room air to flow across the heating coil to mix with the primary air.

Figure 8. Induction Reheat Unit.



The air-and-water reheat system is best suited for applications in which interior zones always require cooling while exterior zones sometimes require heating.

Other air-and-water systems supply hot air and hot water for heating and cold air and cold water for cooling. These systems often use the primary-air system shown in Figure 9. This is a high-pressure air system that allows the use of smaller air ducts. Many air-and-water systems have no return ducts, and the added primary air volume is exhausted directly from the conditioned space. This method represents a savings on equipment cost and reduces the space necessary for ductwork, but it also results in higher operating costs. These systems were popular when energy costs were low, and many are still in use. However, most new systems are designed to conserve energy by recirculating the air.

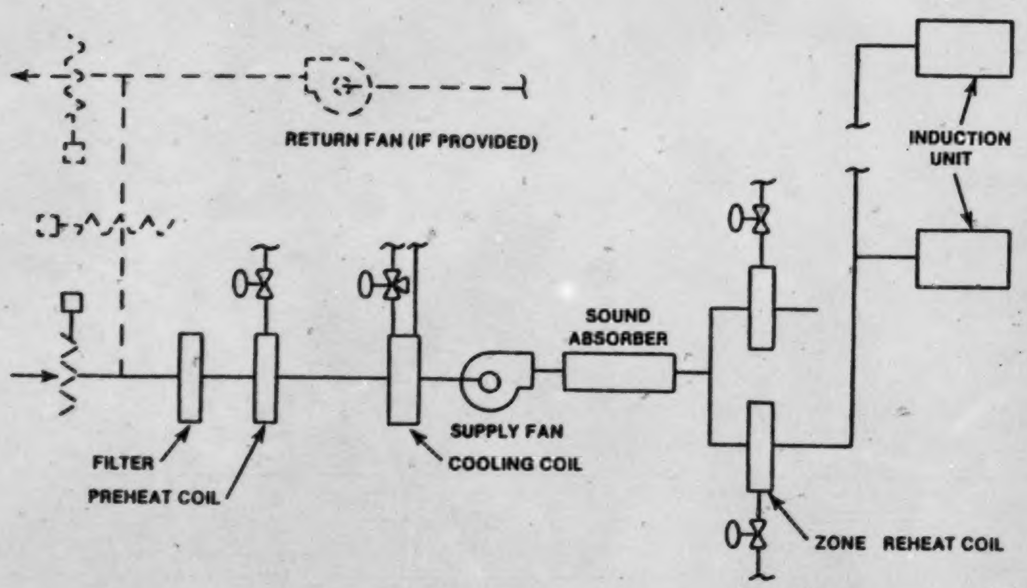

RETURN FAN (IF PROVIDED)
INDUCTION UNIT
SOUND ABSORBER
SUPPLY FAN
COOLING COIL
FILTER
PREHEAT COIL
ZONE REHEAT COIL

Figure 9. Primary Air System.

Figure 10 is an air-water induction unit used with a primary-air system. This particular unit is designed for use with a two-pipe system. The two-pipe system supplies either hot water or cold water to the induction unit, but not both. In such systems, conversion from heating to cooling is accomplished in the central plant. Some two-pipe systems are capable of simultaneously delivering cold water to some zones and hot water to others.

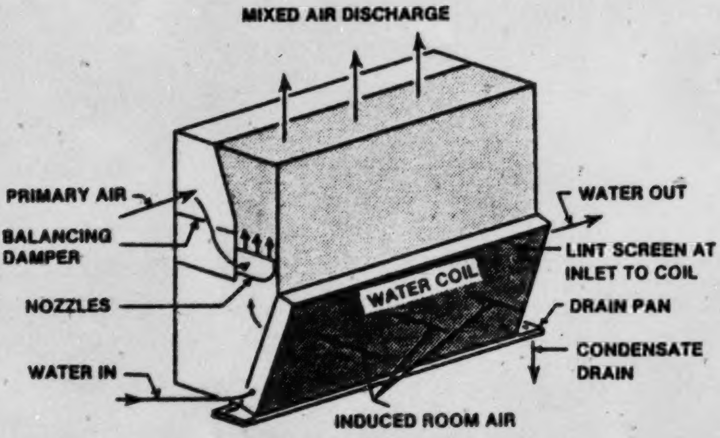

MIXED AIR DISCHARGE
PRIMARY AIR
BALANCING DAMPER
NOZZLES
WATER IN
WATER OUT
LINT SCREEN AT INLET TO COIL
WATER COIL
DRAIN PAN
CONDENSATE DRAIN
INDUCED ROOM AIR

Figure 10. Air-Water Induction Unit.

The induction units of four-pipe systems have two separate water coils, one for heating and one for cooling; and either may be used at any time.

The major advantages of air-and-water systems are the reduction in space necessary for the delivery system and the reduction in energy necessary for the distribution. The small air ducts and water pipes require far less space than the ductwork of all-air systems, and energy losses in liquid-delivery systems are lower than for air systems. Liquid pumps are also more efficient than fans.

Air-and-water systems offer poor humidity control and less ventilation than all-air systems. Their controls also tend to be complex, and maintenance must sometimes be performed in the conditioned space.

Air-and-water systems are commonly used in office and apartment buildings and in other high-rise structures. Four-pipe systems are particularly popular for multiple perimeter spaces where changing solar heat loads produce changing heating and cooling requirements during the day.

ALL-WATER SYSTEMS

All-water systems accomplish both heating and cooling by the distribution of water only. These systems have no air distribution system and, thus, no air ducts.

Each individual space is provided with a fan coil unit, as shown in Figure 11. This unit consists of a circulating fan, a water coil, and a damper system that allows unconditioned outside air to be admitted for ventilation. The fan coil unit in Figure 11 is for use with a two-pipe system in which the entire system is switched from heating to cooling at the central plant. Figure 12 shows a fan coil unit for use in a four-pipe system which can provide either heating or cooling to each individual space.

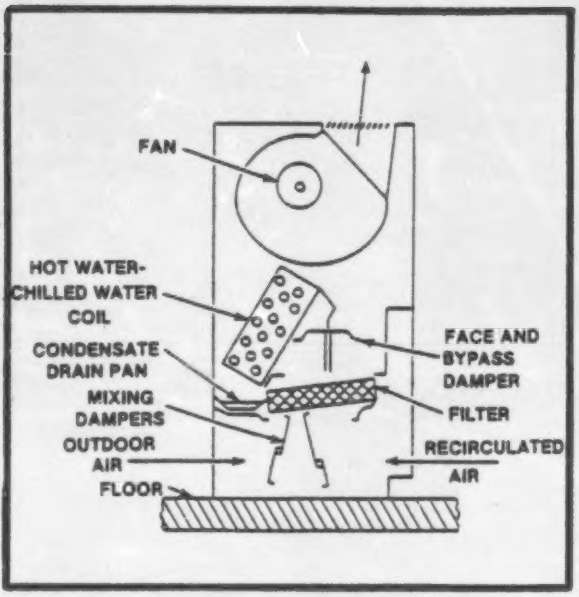

FAN
HOT WATER-
CHILLED WATER
COIL
CONDENSATE
DRAIN PAN
MIXING
DAMPERS
OUTDOOR
AIR
FLOOR
FACE AND
BYPASS
DAMPER
FILTER
RECIRCULATED
AIR

Figure 11. Typical Air Conditioning Unit Ventilator with Combined Hot-Chilled Water Coil.

The greatest advantage of the all-water system is its flexibility for adaption to many modular building arrangements. It is also the easiest system to install in many existing structures. Disadvantages include the lack of humidity control and limited ventilation capabilites. Fan coil units require servicing in the conditioned space and are often noisy.

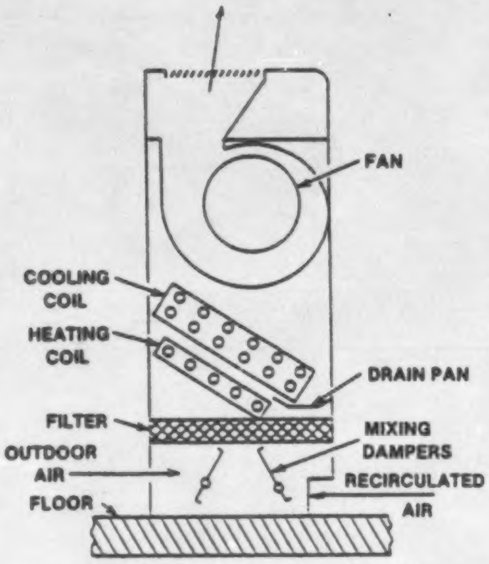

FAN
COOLING COIL
HEATING COIL
DRAIN PAN
FILTER
MIXING DAMPERS
OUTDOOR AIR
RECIRCULATED AIR
FLOOR

Figure 12. Typical Air Conditioning Unit Ventilator with Separate Coils.

UNITARY SYSTEMS

Unitary air conditioners are small systems which cool and dehumidify air in single rooms or small structures. The air is cooled by passing directly across the evaporator of the refrigeration system. Some units have provisions for ventilation with outside air, and some are used in conjuction with gas or oil furnaces or electrical heating elements.

SINGLE-PACKAGE UNITS

Figure 13 is a typical single-package unitary air conditioner for roof-top installation. Figure 14 shows a similar system for through-the-wall installation. The entire refrigeration system, including the blower, is contained in a single package. The unit requires only the connection of a suitable duct system for air delivery.

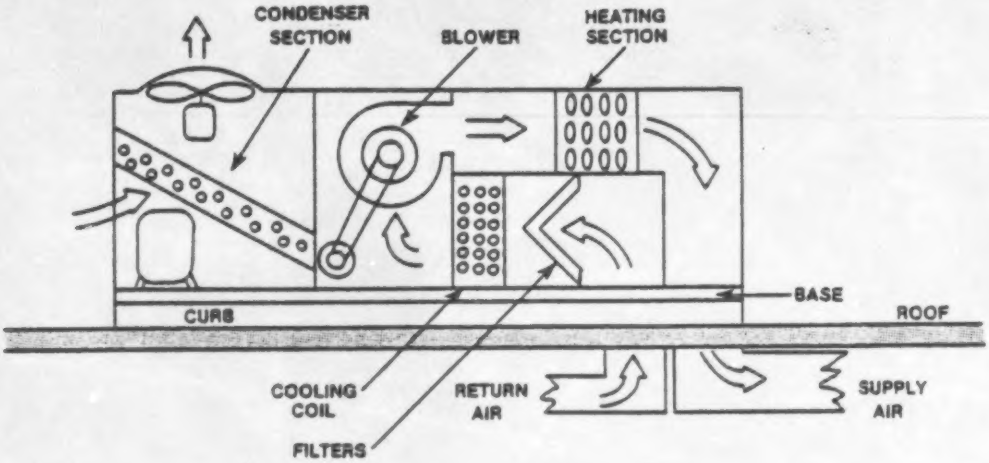

CONDENSER SECTION
BLOWER
HEATING SECTION
BASE
CURB
ROOF
COOLING COIL
RETURN AIR
SUPPLY AIR
FILTERS

Figure 13. Cross-Section of Rooftop Unitary System.

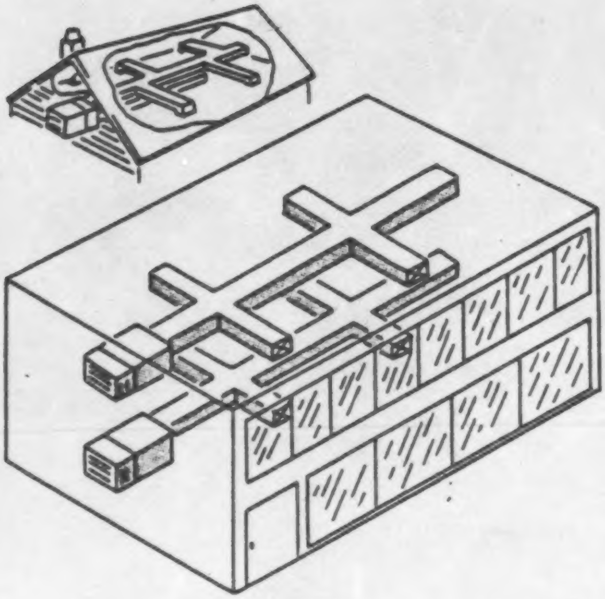


Figure 14. Through-the-wall Installation of Air-cooled, Single-package Unit.

SPLIT SYSTEMS

Figure 15 shows a split unitary air conditioning system. The outside unit consists of the compressor, condenser, and condenser fan. The inside unit contains the metering device, the evaporatory, and the blower. This type of system is often installed in conjunction with a furnace to provide heating in homes. No ventilation is provided by this system.

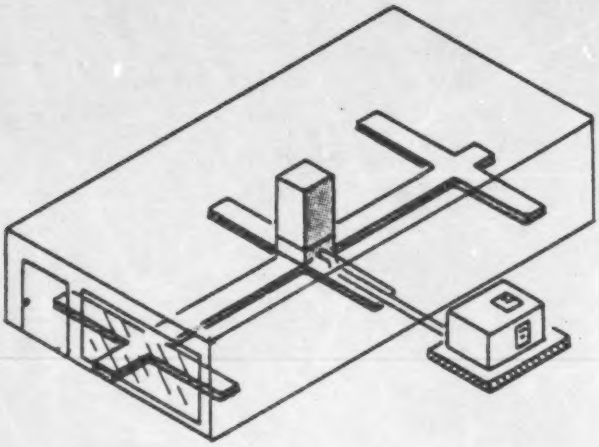


Figure 15. Outdoor Installation of Split Air-Cooled Condensing Unit with Indoor Coil and Counter Flow Furnace.

THROUGH-THE-WALL SYSTEMS

Figure 16 shows a through-the-wall air conditioner system used in many motels. This system is similar to the single-package unit, but it also contains a heating coil. Heating may be accomplished by hot water, steam, or electricity. This unit is usually built into the wall of the room below the windows. No ductwork is required, and the blower provides for air circulation.

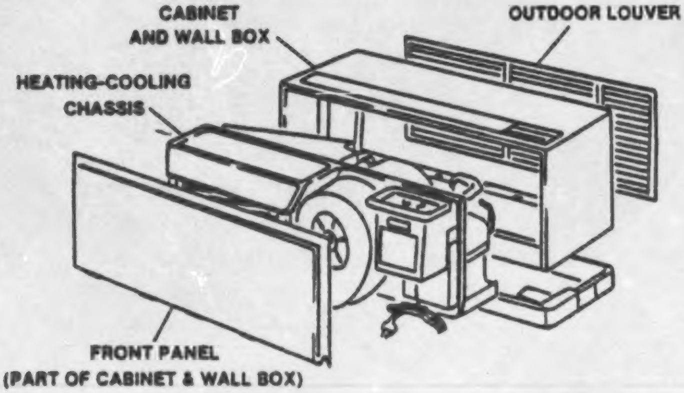

CABINET AND WALL BOX
OUTDOOR LOUVER
HEATING-COOLING CHASSIS
FRONT PANEL (PART OF CABINET & WALL BOX)

Figure 16. Packaged Terminal Air Conditioning with Combination Heating and Cooling Chassis.

ROOM AIR CONDITIONERS

Figure 17 shows the components of a typical room air conditioner. This is a small, self-contained unit designed to be mounted in a window or similar wall opening.

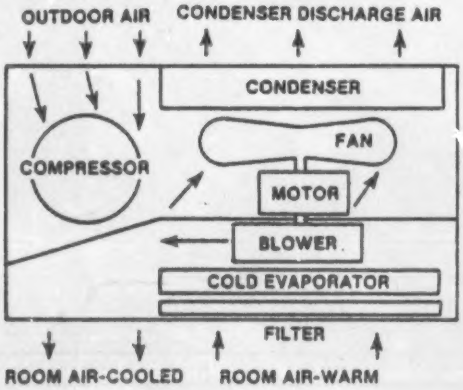
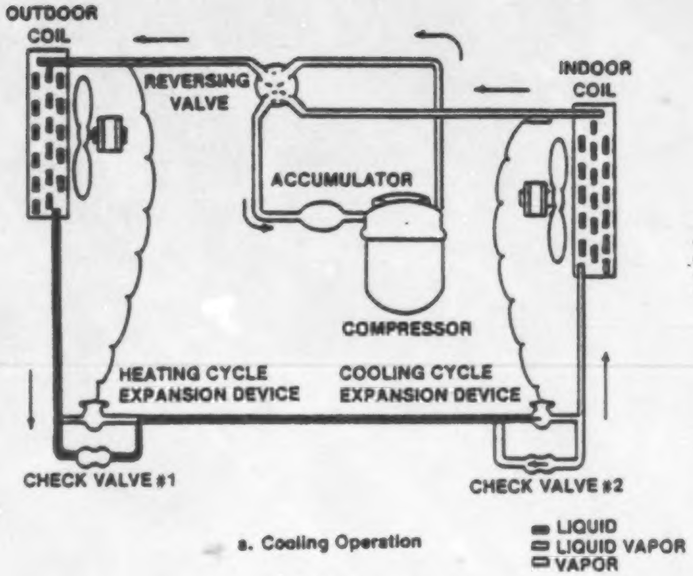

OUTDOOR AIR
CONDENSER DISCHARGE AIR
CONDENSER
FAN
COMPRESSOR
MOTOR
BLOWER
COLD EVAPORATOR
FILTER
ROOM AIR-COOLED
ROOM AIR-WARM

Figure 17. Schematic View of Room Air Conditioner.

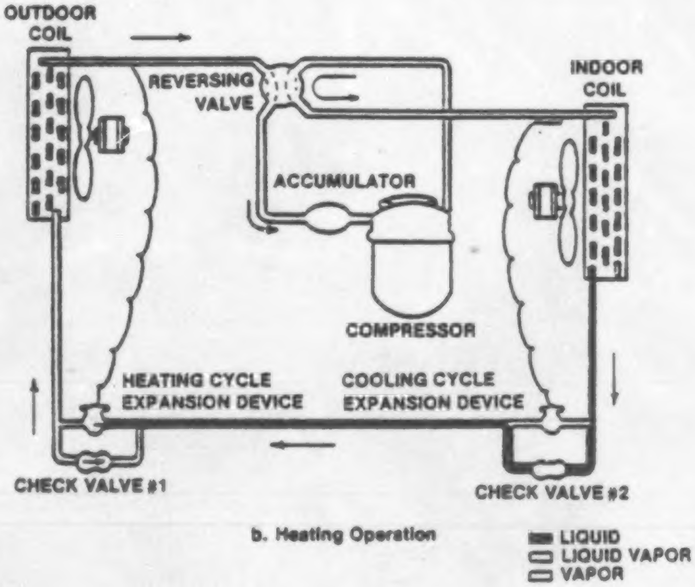
HEAT PUMPS

Heat pumps are unitary systems that provide cooling in the summer and heating in the winter. Figure 18 illustrates heat pump operation. During cooling (Figure 18a) the heat pump functions as an ordinary air conditioner. The indoor coil acts as the condenser and transfers heat energy from the interior.

Heating (Figure 18b) is accomplished by reversing the refrigerant flow with a valve system. The outside coil acts as the evaporator and absorbs heat energy from the cold outside air.


OUTDOOR COIL
REVERSING VALVE
INDOOR COIL
ACCUMULATOR
COMPRESSOR
HEATING CYCLE EXPANSION DEVICE
COOLING CYCLE EXPANSION DEVICE
CHECK VALVE #1
CHECK VALVE #2
LIQUID
LIQUID VAPOR
VAPOR

a. Cooling Operation


OUTDOOR COIL
REVERSING VALVE
INDOOR COIL
ACCUMULATOR
COMPRESSOR
HEATING CYCLE EXPANSION DEVICE
COOLING CYCLE EXPANSION DEVICE
CHECK VALVE #1
CHECK VALVE #2
LIQUID
LIQUID VAPOR
VAPOR

b. Heating Operation

Figure 18. Heat Pump Unitary System.

The inside coil acts as the condenser and releases heat energy into the interior.

The efficiency of the heat pump during cooling is usually slightly less than that of a comparable unitary air conditioner. During heating, a typical heat pump will deliver two units of heat energy for every one unit of electrical energy consumed, thereby cutting in half the electrical energy required for heating. Heat pumps produce only a small temperature rise in the air flowing across the condenser and, thus, never deliver "hot" air. Their efficiency also drops with colder outside air temperatures. Heat pumps are usually equipped with auxiliary electrical heating elements.

SYSTEM CLASSIFICATION

Most small air conditioning systems and some larger ones can be classified as one of the specific systems discussed in this module. Most larger systems, however, combine the features of several system types. One example is a multi-zone air system with hot water induction reheat units in some zones. In large buildings a single system may incorporate different features to serve the specific needs of different zones. In some cases a single building may have several completely separate systems which serve different portions of the structure. Multi-building complexes are often served by central plants that contain a variety of systems that may be interconnected or separate. Large systems often do not fit neatly into any of the categories discussed since each is designed for a specific building and application.

EXERCISES

1. A large single-story building consists of four separate open bays with separate heat loads. Discuss the advantages and disadvantages of the following systems for this application:
   a. Single-zone system.
   b. Primary-air system with hot water induction reheat terminals.
   c. Reheat system with steam coil duct heaters in the central equipment ducts.
   d. Multi-zone system.
   e. Dual-duct system.
2. A large high-rise office building has external zones that are mostly windows and a much larger interior zone. Discuss the advantages and disadvantages of the following systems for this application:
   a. Dual-duct system.
   b. Air-and-water system with induction reheat terminals in external zones.
   c. Four-pipe all-water system.
   d. Multi-zone variable-air-volume system.
3. A new hospital wing requires individual temperature control in each room, close humidity control, and good ventilation. Discuss the advantages and disadvantages of the following systems for this application:
   a. Multi-zone variable-air-volume system with terminal reheat units.
   b. Primary-air system with hot water induction reheat terminals and no return air duct.
   c. Dual-duct system.
   d. Four-pipe all-water system.

4. A new motel consists of several-two-story buildings in which each room has one wall that is mostly glass. Discuss the advantages and disadvantages of the following systems for this application:
   a. Four-pipe all-water system.
   b. Through-the-wall unitary system for each room.
   c. Single-package roof-mounted unitary system for each room.

LABORATORY MATERIALS

Notebook or clipboard.
Pen or pencil.

LABORATORY PROCEDURES

This laboratory consists of a field trip to a large central air conditioning installation. The system visited will be an all-air or air-and-water system which includes a gas- or oil-fired boiler. This system will be visited and studied in more detail on future field trips that are laboratory exercises for other modules in this course.

All notes of this and future field trips must be saved for use in future laboratory exercises. A complete system schematic will be prepared as part of the laboratory for Module HC-07, "Air Handling Equipment."

The purpose of this first visit is to acquaint the student with the overall system. In this laboratory, the student will prepare a diagram of the central air handling equipment and will discuss classification of the system according to the system types discussed in the Subject Matter of this module.

1. Observe the components of the system during the system familiarization tour. Record in the field notebook the data specified in the Data Table and any other information available concerning the system.
2. Sketch the following components in the field notebook (detailed drawings are not necessary):
   a. Boiler.
   b. Compressor.
   c. Chiller.
   d. Cooling tower.
   e. Water pump.
3. Draw a diagram of the air handling equipment of the central system in the field notebook. Show all air ducts and all air processing equipment, including dampers, fans, filters, heating and cooling coils, air washers, and humidifiers or dehumidifiers.
4. If the system has reheat units outside the equipment room, specify their type and location. If induction units are used, include drawings and a discussion of the location of these.
5. After the field trip, prepare a schematic diagram of the central air handling equipment. Identify each major component and state its purpose. Discuss the classification of this system according to the categories described in the Subject Matter.

DATA TABLE

Data Table.

BOILER:

Type: ____________________

Manufacturer: ____________________

Model number: ____________________

Fuel: ____________________

Steam pressure: ____________________

COMPRESSOR:

Type: ____________________

Manufacturer: ____________________

Model number: ____________________

Horsepower of motor: ____________________

CHILLER:

Type: ____________________

Manufacturer: ____________________

Model number: ____________________

COOLING TOWER:

Size: ____________________

Location: ____________________

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Althouse, Andrew D.; Turnquist, Carl H.; and Bracciano, Alfred F. Modern Refrigeration and Air Conditioning. Homewood, IL: The Goodheart-Willcox Company, Inc., 1979.

Carrier Air Conditioning Company. Handbook of Air Conditioning System Design. New York: McGraw-Hill Book Co., 1965.

Croome-Gale, Derek J. and Roberts, Brian M. Air Conditioning and Ventilation of Buildings. New York: Pergamon Press, 1975.

Howell, Ronald H. and Sauer, Harry J., Jr. Environmental Control Principles. New York: American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc., 1978.

TEST

Please circle the appropriate answer.

1. All-air systems ...
   a. do not employ water as a heat exchange medium anywhere in the system.
   b. deliver both heating and cooling effect to the conditioned space by air flow.
   c. supply the entire cooling load by air flow, but may distribute hot water to the conditioned space for heating.
   d. Both a and b are correct.

2. The central plant of a single zone all-air system ...
   a. includes both heating and cooling coils arranged in series.
   b. has a single coil that is used for either heating or cooling.
   c. separates the air to flow over either the heating coils or cooling coils, but not both.
   d. does not provide for outside air ventilation.
   e. Either b or c is true of most single zone systems.

3. Variable volume systems ...
   a. can provide both hot and cold air from the central plant at the same time.
   b. provide the lowest operating cost of any all-air system with individual room controls.
   c. cannot be used if the system load varies more than 20%.
   d. are not suitable for loads comprised of a large number of individual rooms.
   e. Both a and b are correct.
   f. Both c and d are correct.

4. Disadvantages of the dual duct system do not include ...
   a. large spaces needed for duct work.
   b. high initial cost.
   c. complexity of control.
   d. a lesser degree of comfort than multizone systems.
   e. lower system efficiencies than variable volume systems.

5. A multizone system ...
   a. can provide cooling to some zones, while providing heating to others.
   b. mixes hot and cold air in the ducts of the central plant and delivers the mixture to each zone through a single duct.
   c. has a coil section that splits the air so that part of the air flows across the heating coils and part flows across the cooling coils.
   d. All of the above are correct.
   e. Only a and c are correct.

6. Air-and-water systems ...
   a. usually supply both hot and cold water to the conditioned space.
   b. require no conditioning for the air supply.
   c. offer poor humidity control.
   d. have simpler controls and require less maintenance than all-air systems.
   e. All of the above are correct.
   f. Both c and d are correct.

7. All water systems ...
   a. require air delivery ducts, but no return ducts.
   b. are popular for applications where a large number of small rooms require close temperature control.

c. can provide either heating or cooling, but cannot heat one zone while cooling another.

d. provide no humidity control and no ventilation.

e. None of the above are correct.

8. Unitary air-conditioner systems commonly ...

a. do not include return air ducts.

b. consist of a compressor and condenser in an outdoor unit and a fan coil and blower in an indoor unit.

c. employ water-filled fan coils.

d. All of the above are correct.

e. Only a and b are correct.

9. Heat pumps ...

a. provide heating when the indoor coil acts as a condenser.

b. have the same cooling efficiency as ordinary unitary air conditioners.

c. include a reversing valve that changes the direction of refrigerant flow through the metering device.

d. Only a and c are correct.

e. All of the above are correct.

10. Which of the following systems are unlikely to be found in a large office building?

a. Multizone

b. Variable volume

c. Dual duct

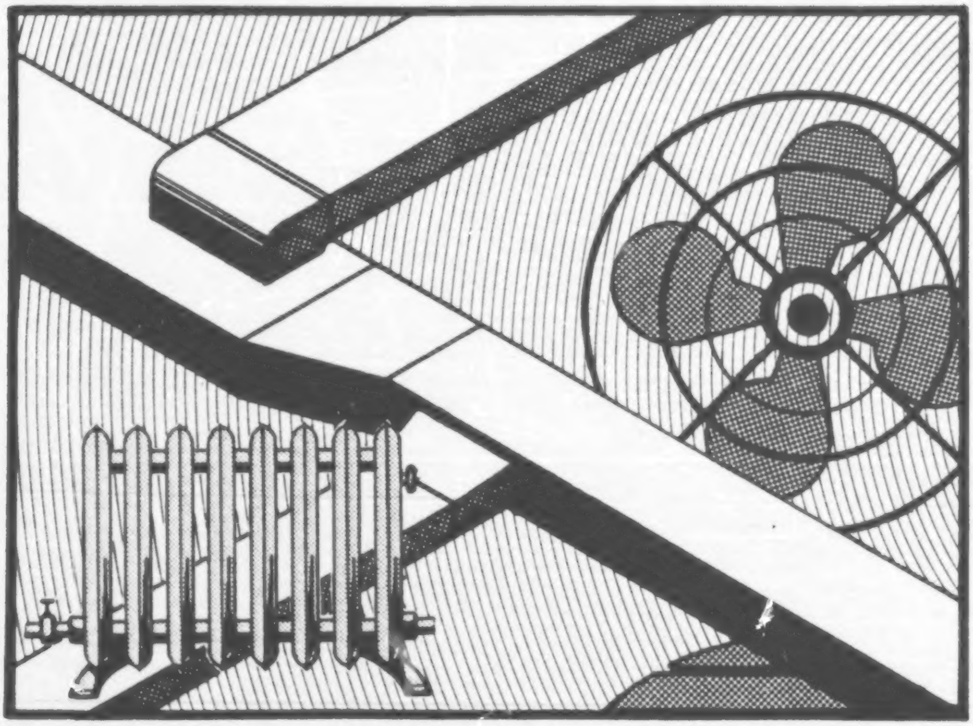
d. Air-and-water

e. All are commonly found in office buildings.

ENERGY TECHNOLOGY

CONSERVATION AND USE

HEATING, VENTILATING, AND AIR CONDITIONING



MODULE HC - 03

REFRIGERATION EQUIPMENT

CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

INTRODUCTION

The heart of an air conditioning system is the refrigeration equipment. This equipment absorbs heat from the air to be conditioned and rejects heat outside the conditioned space. Several heat exchange cycles are often present in a single system. Most large systems contain a chilled water system that transfers energy from a fan coil to a water chiller. A refrigeration cycle removes heat from the water in the chiller and rejects heat into a water-cooled heat exchanger. This water is circulated through a cooling tower where the waste heat is removed by evaporation. Smaller systems typically rely on refrigerant-to-air heat exchangers and use no water coils.

This module describes the equipment and components commonly found in air conditioning systems of all sizes. In the laboratory the student will visit a large central refrigeration plant and collect data on its operation.

PREREQUISITES

The student should have completed Module HC-02, "System Types."

OBJECTIVES

Upon completion of this module the student should be able to:

1. Name the two basic compressor types used in air conditioning systems and explain the function of each with the use of diagrams.

2. State the application and tonnage range of each compressor type.
3. List three types of compressor drives; state conditions in which each drive is used.
4. Describe five methods of compressor capacity control; state advantages and disadvantages of each.
5. Explain the operation of an air-cooled condenser; state three advantages and three disadvantages.
6. Explain the operation of two types of water-cooled condensers.
7. Explain the following terms as they apply to cooling towers:
   a. Counter flow.
   b. Cross flow.
   c. Natural draft.
   d. Induced draft.
   e. Forced draft.
   f. Cooling range.
   g. Approach.
   h. Drift.
   i. Entering wet bulb temperature.
8. Explain the operation of an evaporative condenser.
9. State the condition of the ambient air that affects the capacity of air-cooled condensers and evaporative condensers.
10. Explain the operation of direct expansion coils, dry expansion water chillers, and flooded water chillers.
11. Explain the operation of the following metering devices:
    a. Automatic expansion valve.
    b. Thermostatic expansion valve.
    c. High side float.
    d. Low side float.

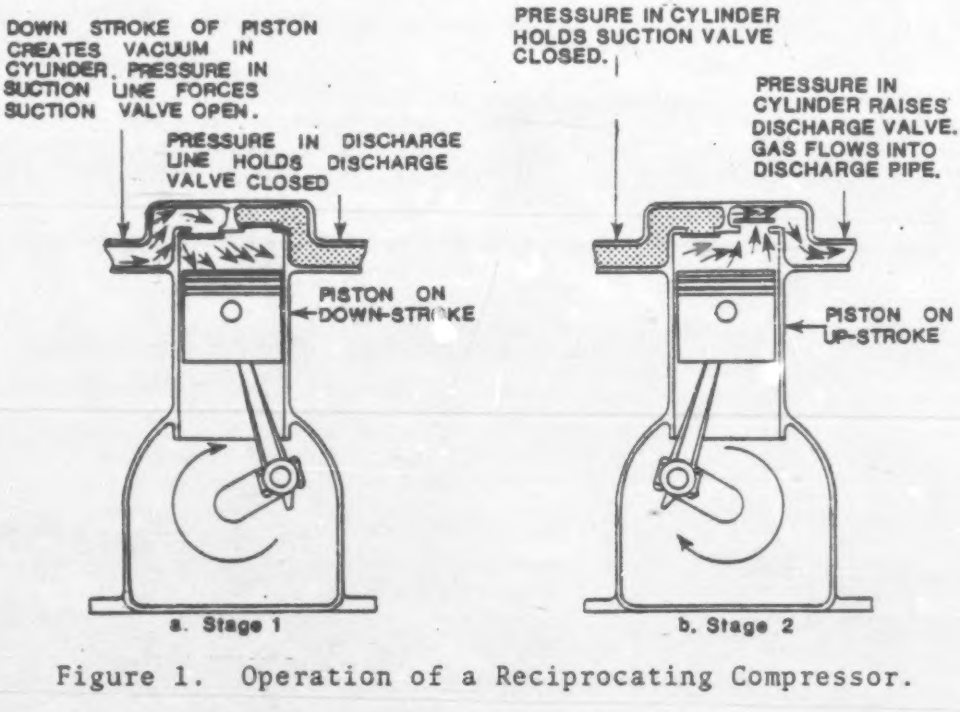
12. State the purpose of each of the following accessories:
    a. Oil separator.
    b. Muffler.
    c. Strainer-drier.
    d. Sight glass.
13. List two basic types of controls used in refrigeration equipment and give two examples of each.
14. Identify the major components of an absorption chiller and state the function of each.
15. Visit a large refrigeration installation. Make drawings of the system components and connections and obtain data on the system.

SUBJECT MATTER

COMPRESSORS

Several types of compressors are used in various refrigeration applications. Most air conditioning systems employ either reciprocating or centrifugal compressors.

Figure 1 illustrates the basic operation of a reciprocating compressor. Refrigerant gas is drawn into the cylinder through the suction valve during the downstroke of the piston and is forced outward through the discharge valve on the upstroke. Cylinders are usually arranged in pairs, with 2 to 16 cylinders to a compressor. Reciprocating compressors are widely used in unitary air conditioners and are the most common type for central systems up to about 125 tons.


DOWN STROKE OF PISTON CREATES VACUUM IN CYLINDER. PRESSURE IN SUCTION LINE FORCES SUCTION VALVE OPEN.
PRESSURE IN DISCHARGE LINE HOLDS DISCHARGE VALVE CLOSED
PISTON ON DOWN-STROKE
PRESSURE IN CYLINDER HOLDS SUCTION VALVE CLOSED.
PRESSURE IN CYLINDER RAISES DISCHARGE VALVE. GAS FLOWS INTO DISCHARGE PIPE.
PISTON ON UP-STROKE

a. Stage 1

b. Stage 2

Figure 1. Operation of a Reciprocating Compressor.

Figure 2 shows the impeller of a centrifugal compressor. Refrigerant gas enters through the center of the impeller. As the impeller rotates, centrifugal force moves the gas through the internal openings of the impeller and outward through the exhaust openings. The cross-sectional area of the refrigerant channels of the impeller is smaller at the exhaust openings than at the intake openings. This results in compression as the refrigerant gas is forced through the impeller. Figure 3 is a diagram showing the construction of a two-stage centrifugal compressor with a self-contained electric motor. Centrifugal compressors are the most common type in air conditioning systems of 125 tons and larger.

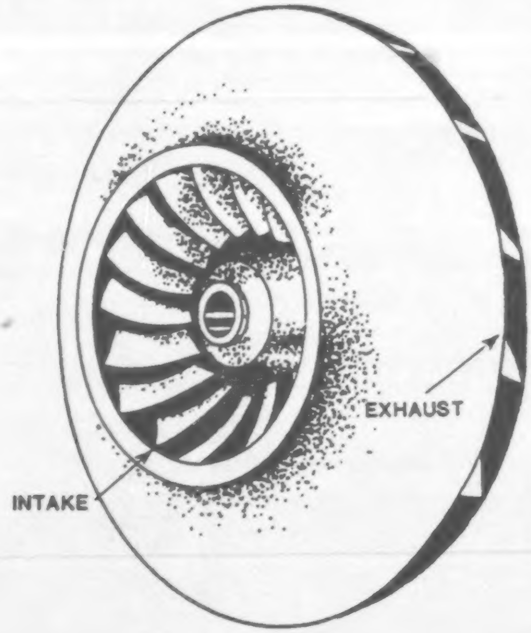


Figure 2. Impeller (rotor) from a Centrifugal Compressor.

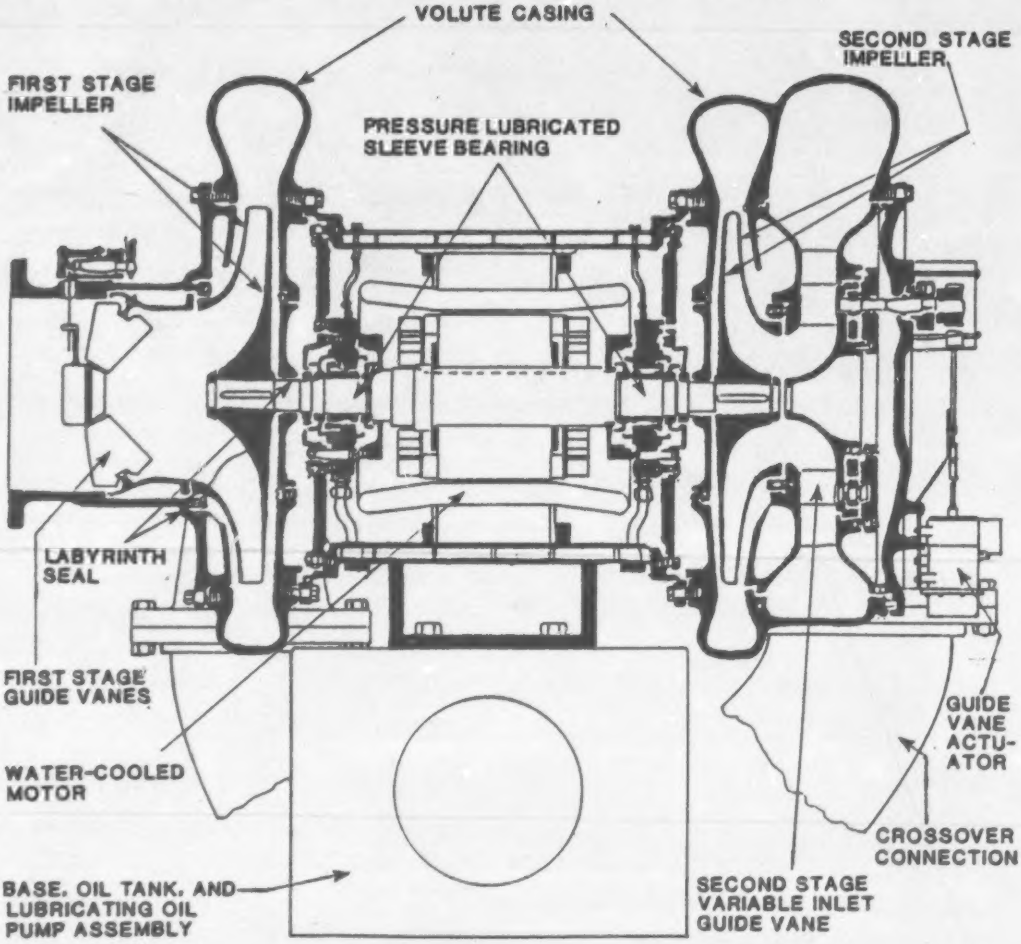

VOLUTE CASING
SECOND STAGE IMPELLER
FIRST STAGE IMPELLER
PRESSURE LUBRICATED SLEEVE BEARING
LABYRINTH SEAL
FIRST STAGE GUIDE VANES
WATER-COOLED MOTOR
GUIDE VANE ACTUATOR
CROSSOVER CONNECTION
BASE, OIL TANK, AND LUBRICATING OIL PUMP ASSEMBLY
SECOND STAGE VARIABLE INLET GUIDE VANE

Figure 3. Two-Stage Centrifugal Compressor.

DRIVES

The compressor may be powered by any source of rotational mechanical energy. The electric motor is the most common power source. Hermetically sealed compressors contain the compressor and electric motor sealed together in a single container. Most small compressors and many large ones are of the hermetically sealed type. Large compressors may also use external electric motors in an "open drive" arrangement in which the motor and compressor are separate.

Internal combustion engines may be used for compressor operation. This may be done in mobile units, back up equipment, and in situations where electrical energy supplies are limited.

Large centrifugal compressors are often powered by steam turbines. This is particularly popular in installations requiring steam for other purposes.

CAPACITY CONTROL

The cooling capacity of an air conditioning system depends upon the rate of evaporation of liquid refrigerant in the evaporator. Capacity control is usually accomplished by controlling the amount of compressed refrigerant gas leaving the compressor for the condenser. In small systems an on-off control turns the compressor drive motor on when the system is in cooling operation. In larger systems a continuous but varying cooling effect is required. This may be accomplished by the following methods.

The capacity of compressors driven by steam turbines may be controlled by controlling the speed of the steam turbine with a valve on the steam inlet. This simplicity of control is one of the advantages of the steam turbine drive.

The capacity of constant speed reciprocating compressors is often controlled by cylinder unloading. A plunger in the cylinder head extends to keep the suction valve open throughout the compressor cycle. The exhaust valve remains closed and the cylinder has no effect. This method is used on large reciprocating compressors to reduce capacity by removing some cylinders from service while others continue to operate.

On some reciprocating compressors in systems of 15 tons and smaller, a hot gas bypass is used for capacity control. When reduced capacity is needed, a valve opens, allowing a portion of the compressor output to bypass the evaporator and condenser and return directly to the suction line. This type of control is unpopular because it is wasteful of compressor drive energy.

Centrifugal compressors are often equipped with adjustable inlet vanes for capacity control, as shown in Figure 3. These vanes reduce the flow rate of inlet refrigerant gas when reduced compressor capacity is required.

HEAT REJECTION EQUIPMENT

AIR-COOLED CONDENSERS

Figure 4 shows the construction of an air-cooled condenser. Hot refrigerant gas enters the inlet from the compressor and flows through the tubing. Heat is conducted through the tubing walls to the fins. Forced air flows across the fins to remove heat. Air-cooled condensers may be installed outdoors using propeller fans or indoors using centrifugal fans and air ducts to deliver and exhaust outside air.

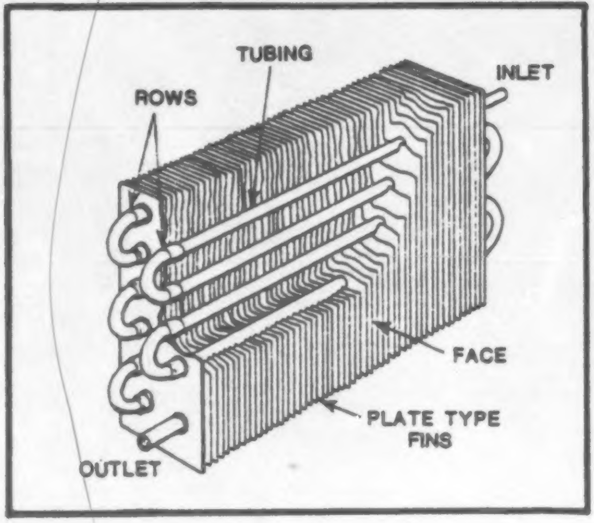


Figure 4. Air-Cooled Condenser.

Air-cooled condensers are common in air conditioning systems in sizes up to 125 tons. Advantages of air-cooled condensers include the following:

- No water requirements.
- Low first cost.
- Low maintenance cost.

The disadvantages are the following:

- Large volumes of air required.
- Possible noise problems.
- Capacity decreases as dry bulb temperature rises.
- High compressor power required at full load.

The capacity of an air-cooled condenser is affected by its size, the air flow across the condenser, and the dry bulb temperature of the air. The wet bulb temperature has no effect since the evaporation of water is not employed in the heat exchange process.

WATER-COOLED CONDENSERS

Some small systems and most large ones employ water-cooled condensers. Figure 5 shows a tube-in-tube condenser.

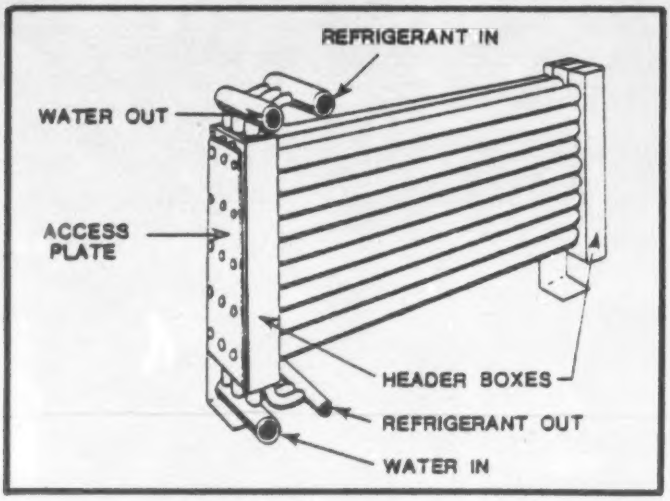


Figure 5. Straight Tube-in-Tube Condenser.

Water flows through the inner tube, and refrigerant gas flows through the outer shell. The refrigerant condenses on the surface of the water-cooled tube. Figure 6 shows a larger shell-and-tube condenser. This unit consists of a large metal cylinder containing water tubes. The refrigerant gas enters through the top of the shell and condenses on the cool water tubes. The condensed liquid collects in the bottom of the shell. This is the most common type of condenser in large refrigeration systems. Water-cooled condensers always provide subcooling of the liquid refrigerant. An increase of 2°F of subcooling increases the system capacity by 1%.

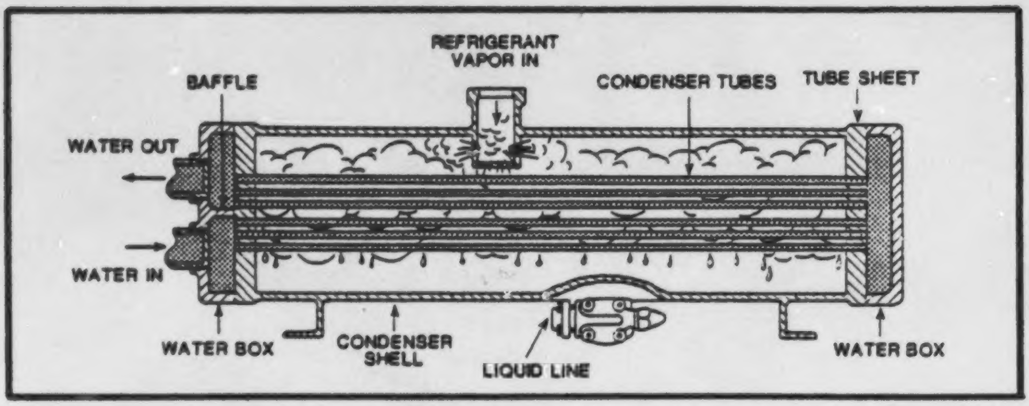

REFRIGERANT VAPOR IN
BAFFLE
CONDENSER TUBES
TUBE SHEET
WATER OUT
WATER IN
WATER BOX
CONDENSER SHELL
LIQUID LINE
WATER BOX

Figure 6. Horizontal Shell-and-Tube Condenser.

The capacity of a water-cooled condenser is dependent upon the inlet water temperature, the water flow rate, and the temperature of the entering refrigerant gas. The amount of subcooling and the capacity may be increased by lowering the inlet water temperature, increasing the water flow rate, or increasing the condensing pressure. The pressure is increased by increasing compressor power.

COOLING TOWERS

The water from the water-cooled condenser is circulated by pump to a cooling tower where heat is rejected through evaporation. Makeup water is added to offset the loss through evaporation.

Figure 7 shows the basic construction of a cooling tower. Water enters through a water distribution box in the top of the tower. The water falls through stacks of wooden decking arranged so the water from the edge of one piece of decking falls in the center of the next lower piece. The decking is arranged to present the maximum water surface to the air for evaporative cooling. This cooled water is collected in the bottom of the cooling tower and then returned to the water-cooled condenser.

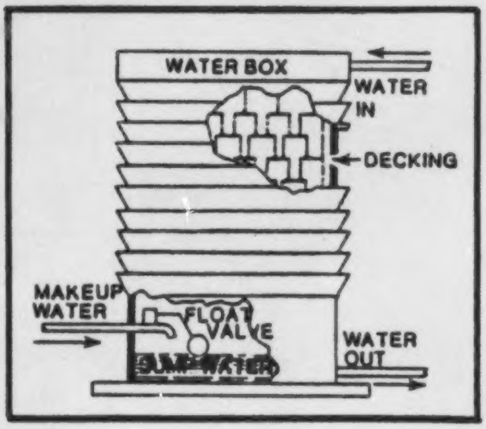

WATER BOX
WATER IN
DECKING
MAKEUP WATER
FLOAT VALVE
SUMP WATER
WATER OUT

Figure 7. Cooling Tower — Splash Deck Type.

Cooling towers may use natural draft air flow or air flow supplied by a fan. If the direction of air flow is opposite the direction of water flow (vertical air flow), the tower is classified as a "counterflow" tower. In "cross-flow" towers, the air flow is perpendicular to the water flow (horizontal air flow). Fans may be located to provide either a forced draft or an induced draft (Figure 8).

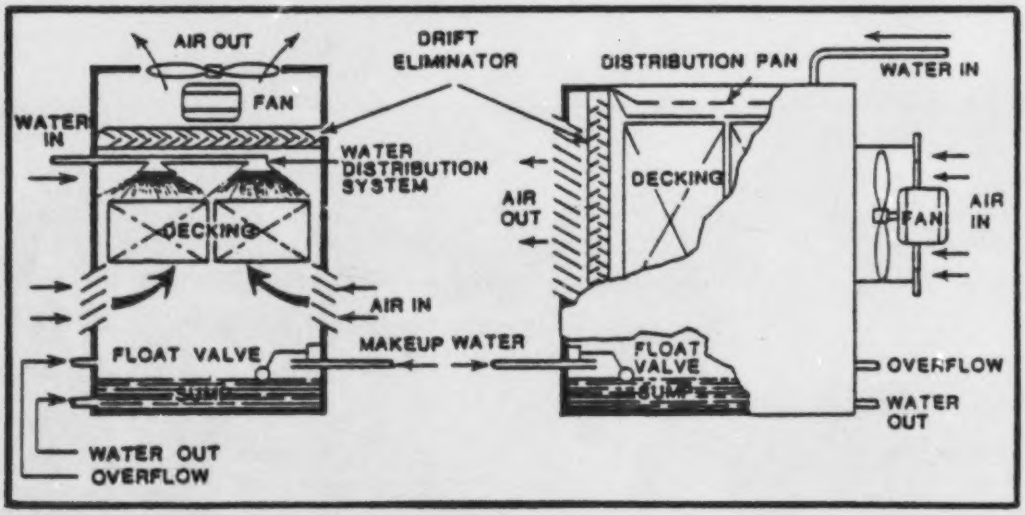

AIR OUT
DRIFT ELIMINATOR
DISTRIBUTION PAN
WATER IN
FAN
WATER IN
WATER DISTRIBUTION SYSTEM
AIR OUT
DECKING
DECKING
FAN
AIR IN
AIR IN
FLOAT VALVE
MAKEUP WATER
FLOAT VALVE
SUMP
SUMP
OVERFLOW
WATER OUT
WATER OUT
OVERFLOW

Figure 8. Types of Mechanical Draft Cooling Towers.

Figure 9 shows the cooling water circuit of a water-cooled condenser and cooling tower combination. The cooling tower must be located above the level of the centrifugal water pump so gravity will provide a constant water supply to the pump.

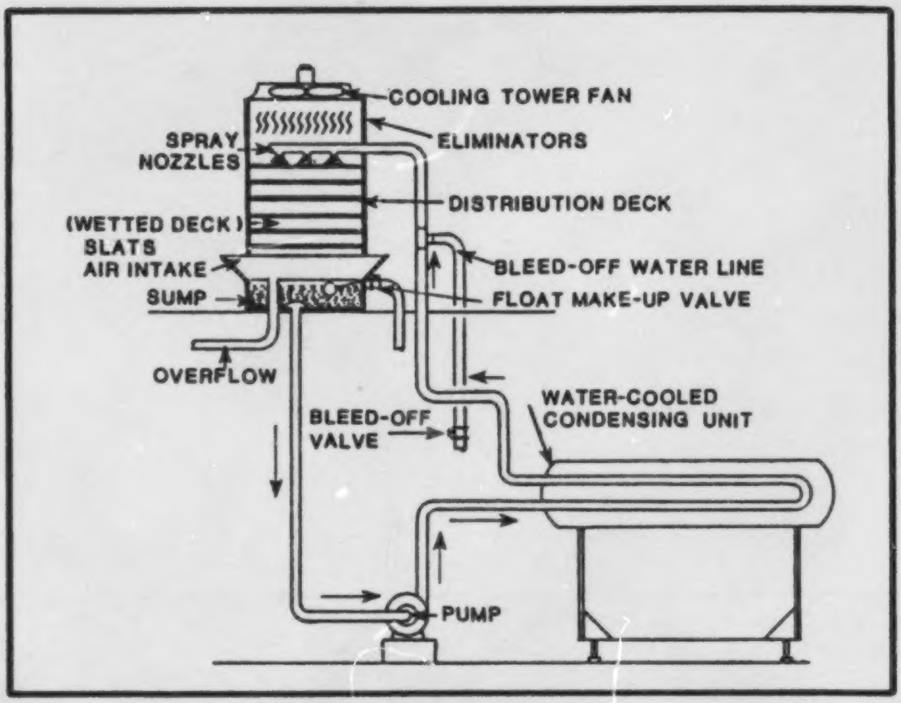

COOLING TOWER FAN
SPRAY NOZZLES
ELIMINATORS
DISTRIBUTION DECK
(WETTED DECK) SLATS
AIR INTAKE
BLEED-OFF WATER LINE
SUMP
FLOAT MAKE-UP VALVE
OVERFLOW
WATER-COOLED CONDENSING UNIT
BLEED-OFF VALVE
PUMP

Figure 9. Schematic Diagram of a Mechanical Draft Cooling Tower.

Cooling towers provide a cooling effect through evaporation and, therefore, are dependent upon the wet bulb temperature of the air. Thus, cooling towers lose capacity during hot humid weather. The evaporation of one pound of water removes 970 Btu of heat. This gives an evaporation rate of 1.8 gallons of water per hour for each ton of air conditioning. Cooling towers are equipped with draft eliminators that reduce the loss of water droplets from the tower.

The following terms are often used in the description of cooling tower performance:

- Cooling range is the temperature difference (°F) between the hot water entering the tower and the cool water leaving it.
- Approach is the temperature difference (°F) between the cold water leaving the tower and the wet bulb temperature of the surrounding air.
- Ambient wet bulb temperature is the wet bulb temperature of the surrounding air that is not being affected by the warm, moist discharge air of the tower.
- Entering wet bulb temperature is the wet bulb temperature of the air that actually enters the tower. This air often includes the recirculation of some of the exhausted air; thus the ambient wet bulb temperature may not provide an accurate evaluation of performance.

The capacity of a cooling tower may be controlled by the use of multi-speed fans or adjustable louvers.

Cooling towers are the most popular type of heat rejection equipment because they afford large capacity in a relatively small space and because of the simplicity of the piping used. The primary disadvantages of cooling towers are the need for regular maintenance and the possibility of damage due to freezing in cold weather.

EVAPORATIVE CONDENSERS

An evaporative condenser is a combination of a water-cooled condenser and a cooling tower in a single package. Figure 10 shows two configurations of evaporative condensers. The operation is similar to that of the cooling towers. Evaporative condensers are most popular in installations in which the condensers are located inside the equipment room and outside air is supplied and exhausted by ducts. Such a system is shown in Figure 11. If the cooling is to take place at a remote location, a water-cooled condenser and cooling tower are used to eliminate the need to pipe refrigerant outside the equipment room.

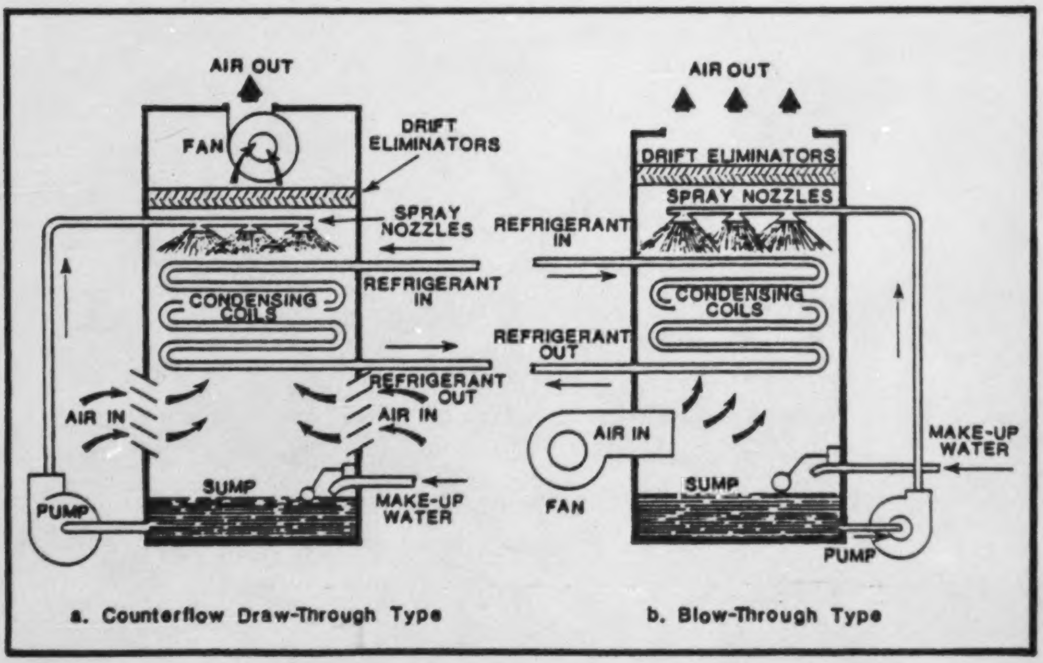

AIR OUT
FAN
DRIFT ELIMINATORS
SPRAY NOZZLES
CONDENSING COILS
REFRIGERANT IN
REFRIGERANT OUT
AIR IN
AIR IN
SUMP
PUMP
MAKE-UP WATER
a. Counterflow Draw-Through Type
AIR OUT
DRIFT ELIMINATORS
SPRAY NOZZLES
REFRIGERANT IN
CONDENSING COILS
REFRIGERANT OUT
AIR IN
FAN
SUMP
MAKE-UP WATER
PUMP
b. Blow-Through Type

Figure 10. Evaporative Condensers.

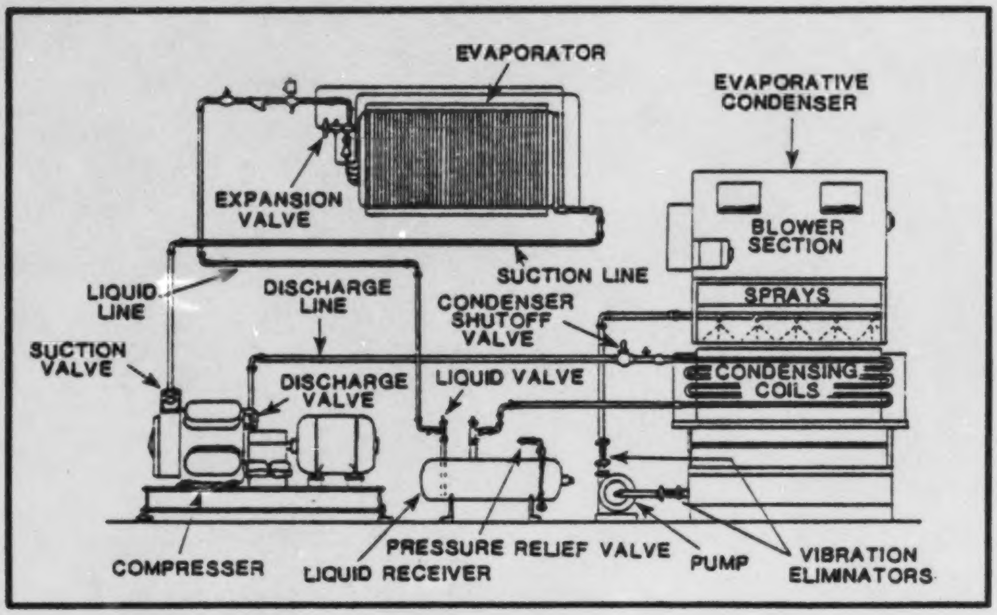

EVAPORATOR
EVAPORATIVE CONDENSER
EXPANSION VALVE
BLOWER SECTION
SUCTION LINE
LIQUID LINE
DISCHARGE LINE
CONDENSER SHUTOFF VALVE
SPRAYS
SUCTION VALVE
DISCHARGE VALVE
LIQUID VALVE
CONDENSING COILS
PRESSURE RELIEF VALVE
COMPRESSER
LIQUID RECEIVER
PUMP
VIBRATION ELIMINATORS

Figure 11. Evaporative Condenser Installation.

EVAPORATORS

Evaporators are classified according to two sets of criteria: as dry expansion or flooded and as air coils or water chillers. In dry expansion evaporators, the liquid refrigerant enters one end of a tube, expands, and evaporates. Refrigerant gas leaves the other end of the tube. Flooded evaporators consist of a reservoir of liquid refrigerant that boils to produce a cooling effect. The refrigerant gas is exhausted from above the liquid surface by the compressor.

DIRECT EXPANSION COILS

Most small air conditioning systems employ dry expansion coils that resemble the condenser shown in Figure 4. The refrigerant evaporates inside the tubes, absorbing heat energy from the tube walls. Air is forced across the fins attached to the coil and is cooled.

WATER CHILLERS

Most central air conditioning systems use water chillers. The evaporating refrigerant chills water that is then circulated through a fan coil. Water chillers may be of either the dry expansion or the flooded type. Figure 12 shows a dry expansion chiller that is often used with refrigerant R-22. The liquid refrigerant enters the lower part and flows through the tubes. Refrigerant gas is exhausted through the upper part. The water flows around the tubes through a set of internal baffles.

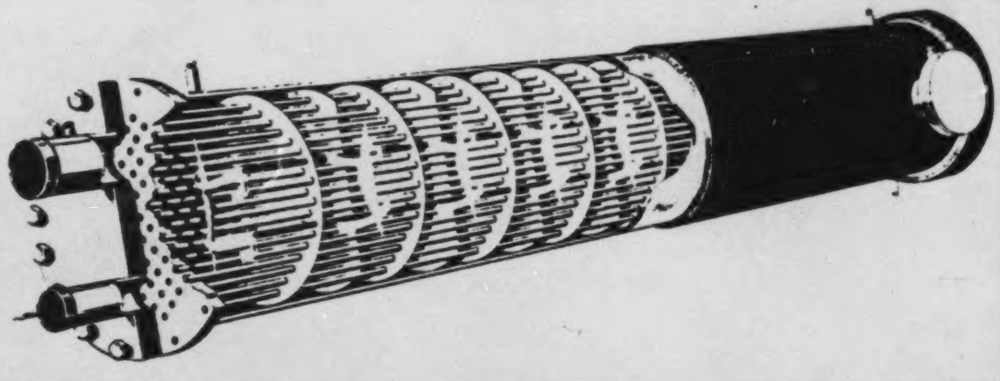


Figure 12. Dry Expansion Chiller.

In a flooded water chiller, the water flows through tubes that are emersed in a cylinder partially filled with liquid refrigerant.

METERING DEVICES

AUTOMATIC EXPANSION VALVE

Figure 13 is a schematic diagram of an automatic expansion valve. Liquid refrigerant enters the valve from the left. The liquid line pressure P_3 forces the movable needle downward, as does atmospheric pressure P_1 and spring force F_1. The needle is forced upward by spring force F_2 and

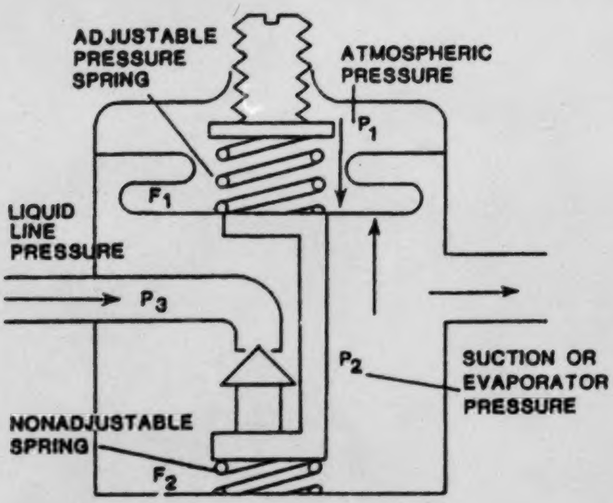

ADJUSTABLE PRESSURE SPRING
ATMOSPHERIC PRESSURE
P1
F1
LIQUID LINE PRESSURE
P3
P2
SUCTION OR EVAPORATOR PRESSURE
NONADJUSTABLE SPRING
F2

Figure 13. Automatic Expansion Valve.

evaporator pressure P_2. While the compressor is running, P_2 is low and P_3 is sufficient to open the valve to allow liquid refrigerant to flow. When the compressor stops, the low side pressure P_2 rises until the valves close.

The automatic expansion valve is designed to produce a constant pressure drop; it can be adjusted by a screw that changes spring force F_1. This metering device is common in refrigerators but is seldom used in air conditioning systems.

THERMOSTATIC EXPANSION VALVE

Figure 14 shows a thermostatic expansion valve. The construction is the same as the automatic expansion valve, except P_1 is no longer atmospheric pressure. The upper portion of the valve is connected by a capillary tube to

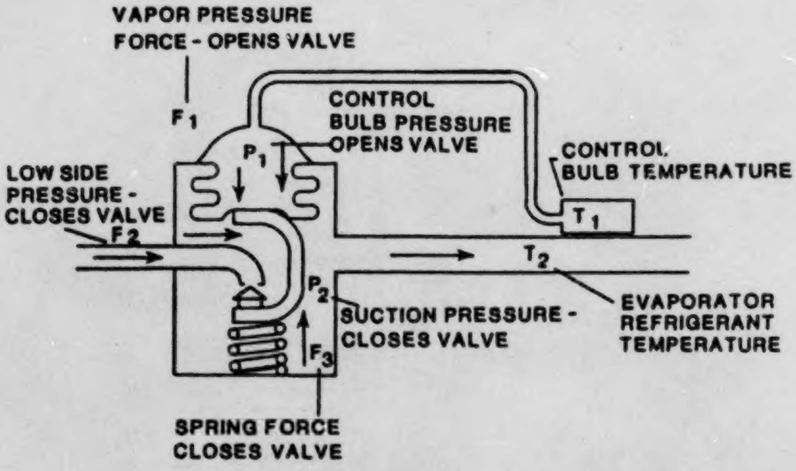

VAPOR PRESSURE FORCE - OPENS VALVE
F1
CONTROL BULB PRESSURE OPENS VALVE
P1
CONTROL BULB TEMPERATURE
T1
LOW SIDE PRESSURE - CLOSES VALVE
F2
T2
P2
SUCTION PRESSURE - CLOSES VALVE
EVAPORATOR REFRIGERANT TEMPERATURE
F3
SPRING FORCE CLOSES VALVE

Figure 14. Thermostatic Expansion Valve.

a control bulb. The bulb is attached to the suction line and is charged with refrigerant. The pressure P_1 depends on the temperature of the control bulb T_1 – which in turn depends upon the suction line temperature T_2. If T_1 drops, P_1 drops; and the valve closes slightly, regulating the flow of refrigerant.

Thermostatic expansion valves are widely used in many refrigeration and air conditioning systems.

HIGH PRESSURE FLOAT

Figure 15 shows a high pressure float used in many air conditioning systems. Liquid refrigerant enters the receiver from the condenser. As the liquid level rises, the float rises, opening the needle valve. When the liquid level drops, the valve closes.

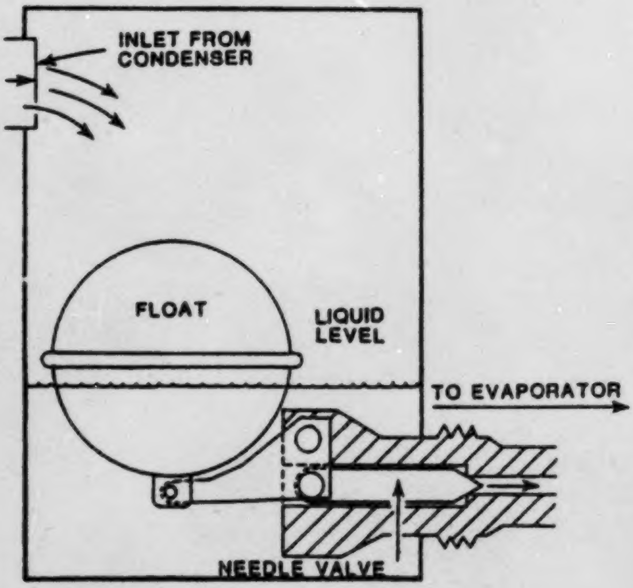


Figure 15. High Pressure Side Float Refrigerant Control Mechanism.

LOW SIDE FLOAT

Figure 16 is a low side float. This particular design uses a float pan, but solid or hollow floats may also be used. This metering device maintains a constant liquid refrigerant level in a flooded evaporator.

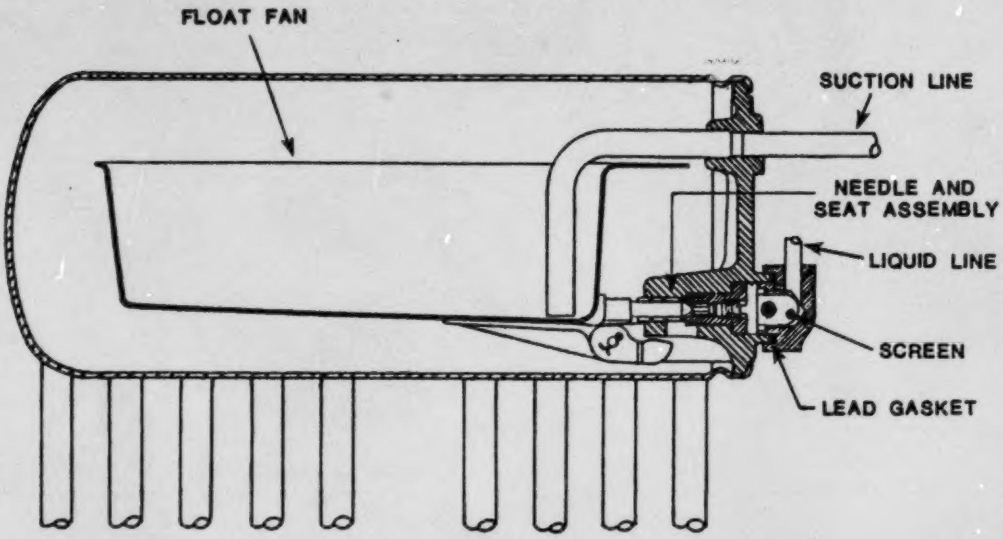

FLOAT FAN
SUCTION LINE
NEEDLE AND SEAT ASSEMBLY
LIQUID LINE
SCREEN
LEAD GASKET

Figure 16. Low Pressure Side Float Refrigerant Control.

ACCESSORIES

OIL SEPARATOR

An oil separator (Figure 17) is included in most air conditioning systems to remove oil from the refrigerant gas as it leaves the compressor. Hot gas and oil enter from the left and travel downward through a pipe and screen. The oil collects in the bottom of the separator and is returned to the compressor. The hot refrigerant gas travels through the pipe at the right to the condenser. Oil separators are never 100% efficient; therefore some oil always circulates with the refrigerant.

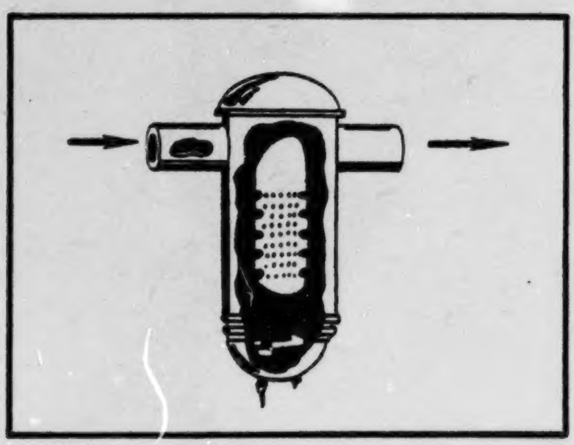


Figure 17. Oil Separator.

MUFFLERS

Reciprocating compressors are usually equipped with mufflers similar to automobile mufflers. These mufflers reduce noise and smooth the flow of gas before it reaches the condenser. Mufflers are sometimes combined with oil separators.

HEAT EXCHANGERS

A heat exchanger (Figure 18) transfers heat from the warm liquid to the cold suction gas. This action subcools the liquid, increasing system capacity; and it superheats the suction gas to protect the compressor from liquid refrigerant.

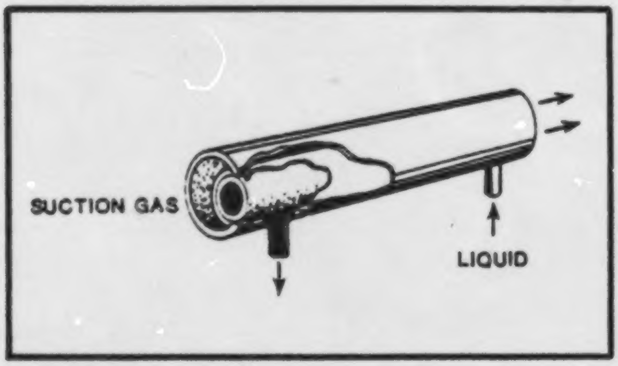


Figure 18.
Heat Exchanger.

STRAINER-DRIER

The strainer drier is installed in the liquid line. It serves two purposes: it strains any solid particles from the liquid before it reaches the metering device and it contains a disiccant that absorbs any water that may be present.

SIGHT GLASS

Figure 19 shows the sight glass common on smaller air conditioning systems. The sight glass, located in the liquid line, should be completely filled with liquid refrigerant during normal operation. This particular model also contains a moisture indicator that can be used to determine when the drier should be changed.

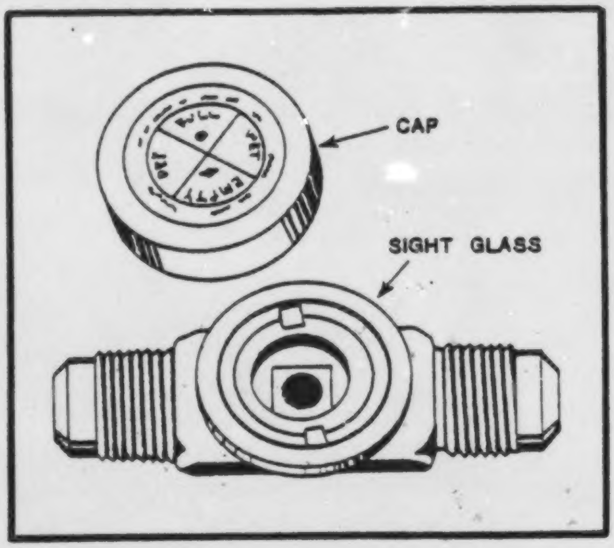


Figure 19. Sight Glass and Moisture Indicator Combination.

CONTROLS

Several types of controls can be used to regulate refrigerant and water flow, turn off or on compressor motors, and control the compressor capacity. Some of these control mechanisms are a part of normal system control; others are safety features. The same type of control mechanism may be a part of normal system operation in one system, a safety feature in another, and entirely missing in a third. All control mechanisms are either pressure sensors or temperature sensors.

TEMPERATURE CONTROLS

The control bulb of the thermostatic control valve is one type of temperature sensor. Electronic temperature sensors also are used. The temperature of the suction line may be used to control refrigerant flow and compressor capacity control. It can serve as a safety feature to turn the compressor drive off if there is danger of liquid refrigerant entering the compressor. Chilled water flow through the fan coils also is controlled by temperature actuated valves.

PRESSURE CONTROLS

Pressure sensors located in either the hot gas line or the suction line can be used to control compressor capacity or as a safety feature. These controls can be connected in a variety of ways. One common application is a switch that turns the compressor motor off (or reduces compressor capacity) when the low side pressure drops below a certain level. The same control can be used to turn the compressor on when the pressure rises. High side pressure controls are often included as safety devices.

SYSTEM CONTROL

Control of an air conditioning system can be accomplished in several ways. One of the most common is to use a thermostatically controlled water valve to allow cold water to flow through the fan coil or to bypass the coil and return to the chiller. If the water bypasses the fan coil, the chiller temperature and the temperature of the suction also drop. A thermostatic control valve senses the drop in suction line temperature and reduces liquid refrigerant flow into the evaporator. This reduces the suction line pressure, and a low suction pressure control either reduces compressor capacity or turns the compressor off.

SYSTEM CONFIGURATIONS

A variety of system configurations are common – ranging from individual components connected by piping to packaged water chillers. Figure 20 shows a reciprocating large package chiller. The water-cooled condenser and the water chiller (evaporator) are the cylinders located below the compressor. Such a package only requires connection to a cooling tower and a fan coil to be placed in operation.

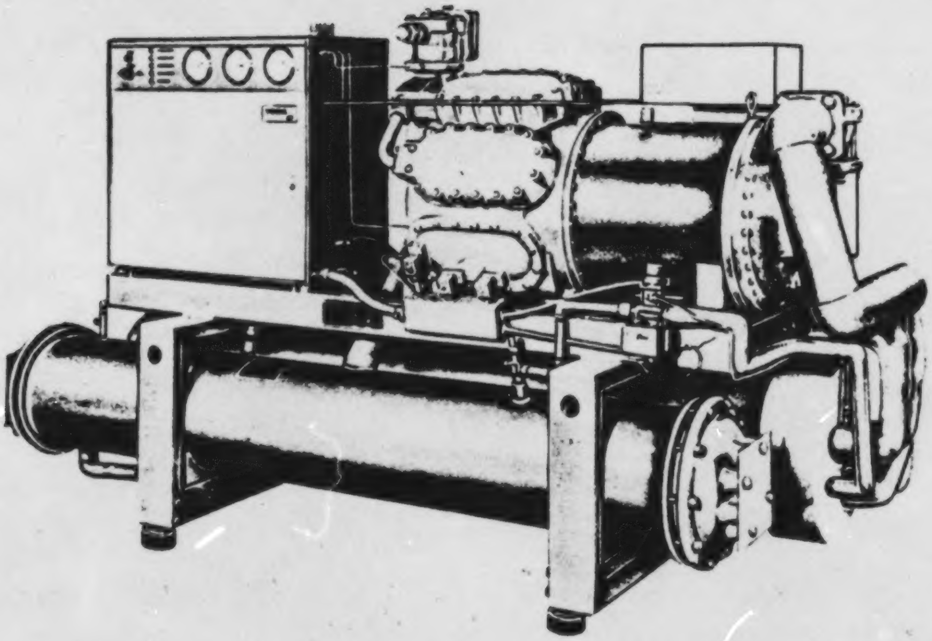


Figure 20. Reciprocating Large Package Chiller.

Figure 21 is a centrifugal chiller assembly. The single cylinder below the compressor is divided into two sections. One is the evaporator, and the other is the condenser.

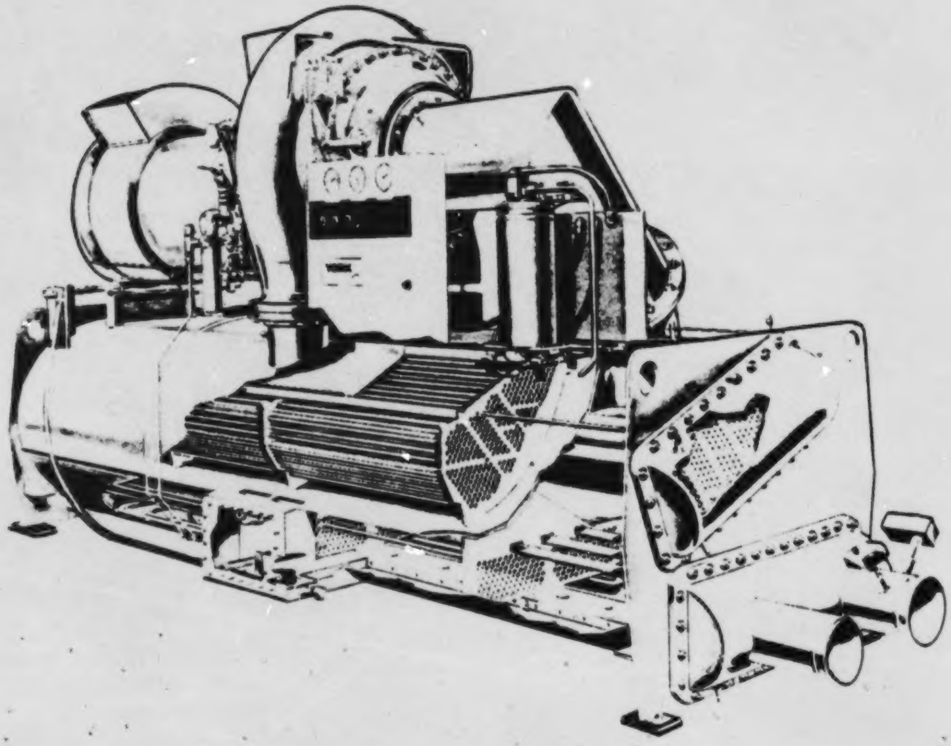


Figure 21. Centrifugal Chiller Assembly.

ABSORPTION CHILLERS

An absorption chiller produces a cooling effect through the direct application of heat energy. Absorption refrigeration can be explained by following rejected heat energy as it travels through the systems.

EVAPORATOR

The evaporator (Figure 22) consists of a tube coil inside a vacuum chamber. Water, the refrigerant, is circulated by a pump. The water sprays over the evaporator coil and boils away at the low pressure, removing heat from the evaporator coil and cooling the water flowing through it. This chilled water is supplied to a fan coil.

ABSORBER

The absorber (Figure 23) is located below the evaporator in the same vacuum shell. It consists of a condenser coil and a reservoir of lithium bromide (LiBr) solution. The condenser carries water returning from a cooling tower. (Approximate temperatures are given in Figure 23 in degrees Fahrenheit.) A spray wets the surface of the condenser with the LiBr solution. This solution absorbs water vapor readily, heating the water flowing through the condenser and maintaining a low pressure inside the vacuum shell.

GENERATOR

Heat is added to the system in the generator (Figure 24), which is located in a second cylindrical shell. The purpose of the generator is to separate the lithium bromide solution from the absorber into concentrated LiBr solution and water. It consists of a coil that carries steam and hot water through the LiBr solution. This causes some of the water to evaporate. The concentrated LiBr solution returns to the absorber.

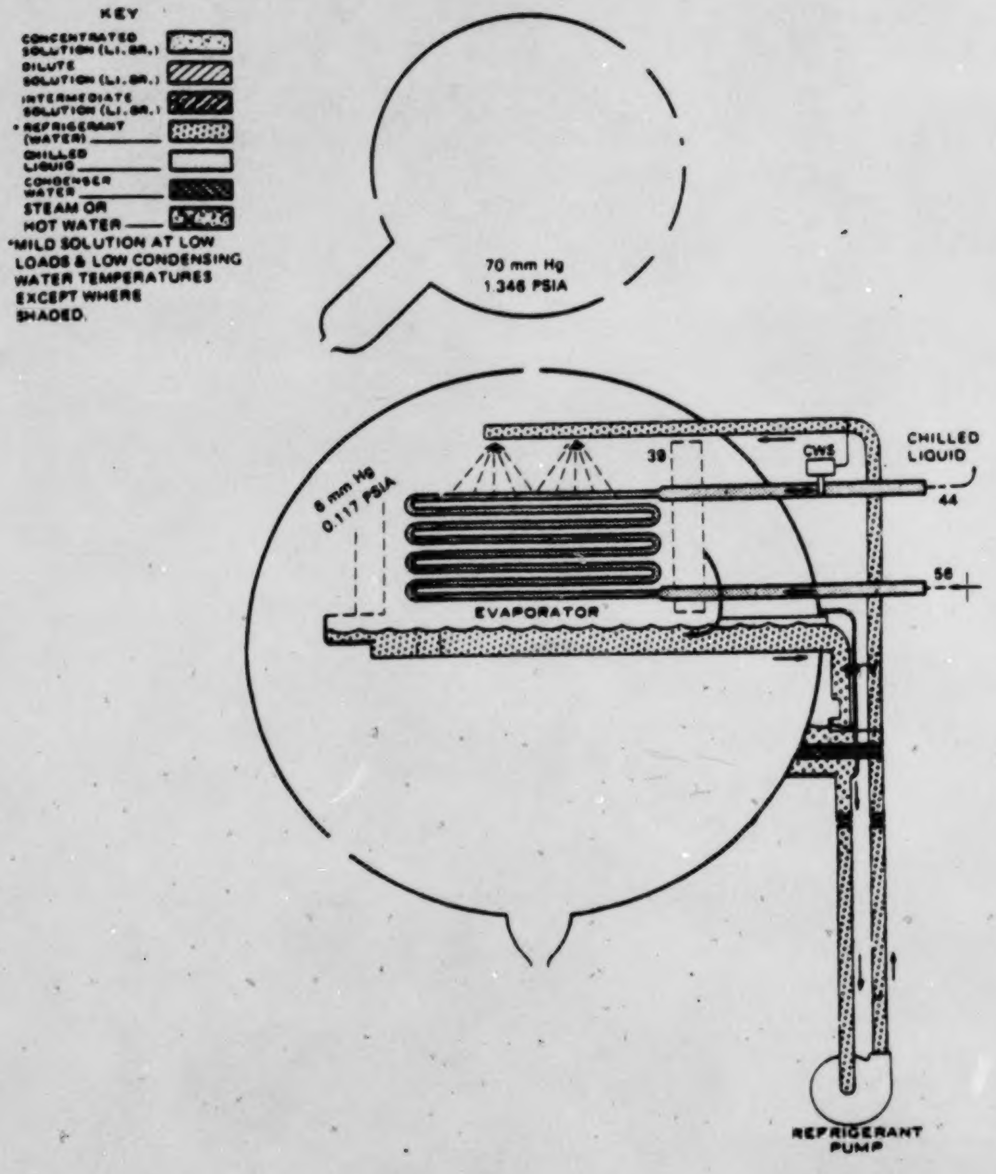

KEY
CONCENTRATED SOLUTION (LI. BR.)
DILUTE SOLUTION (LI. BR.)
INTERMEDIATE SOLUTION (LI. BR.)
*REFRIGERANT (WATER)
CHILLED LIQUID
CONDENSER WATER
STEAM OR HOT WATER
*MILD SOLUTION AT LOW LOADS & LOW CONDENSING WATER TEMPERATURES EXCEPT WHERE SHADED.
70 mm Hg
1.346 PSIA
6 mm Hg
0.117 PSIA
39
CWS
CHILLED LIQUID
44
56
EVAPORATOR
REFRIGERANT PUMP

Figure 22. Evaporator.

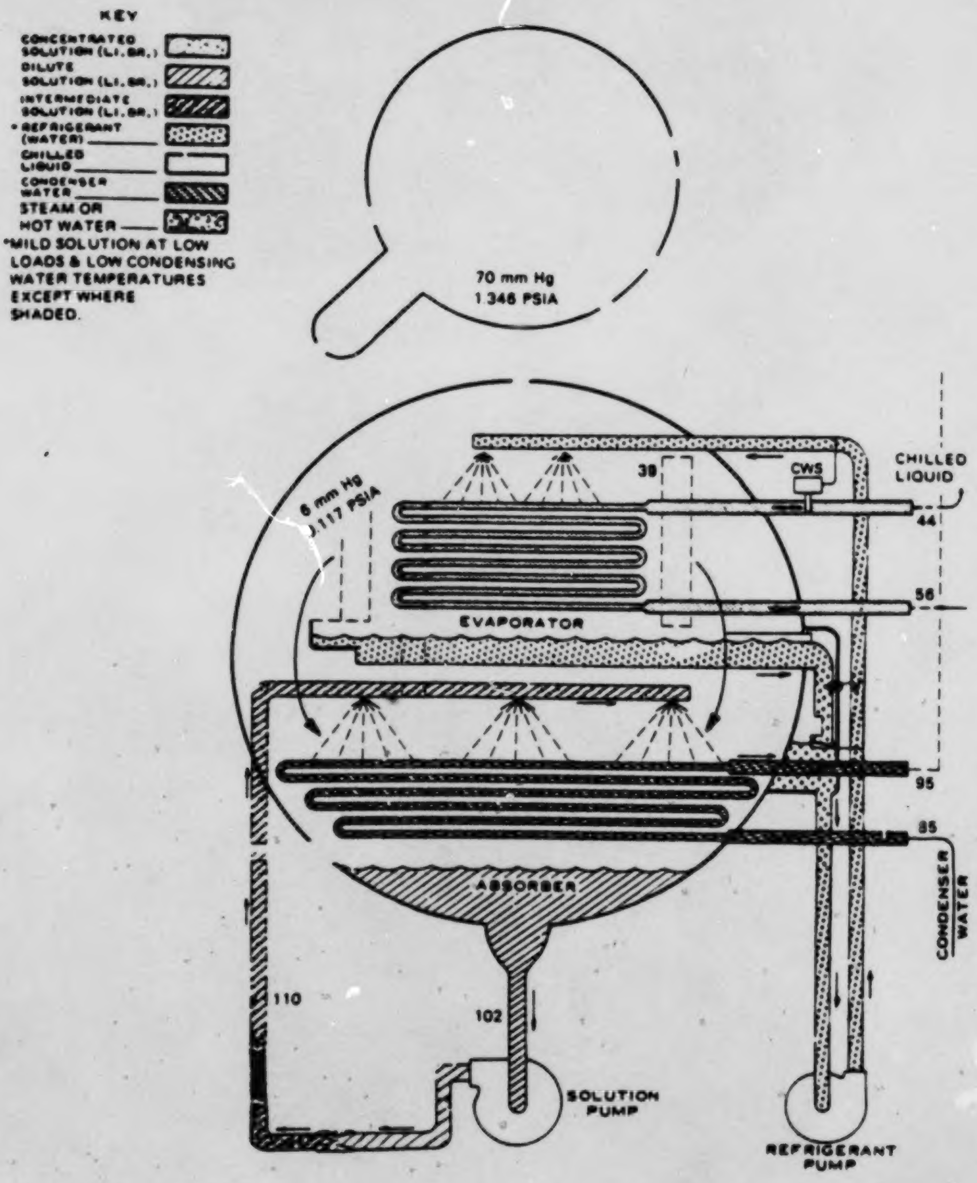

KEY
CONCENTRATED SOLUTION (LI. BR.)
DILUTE SOLUTION (LI. BR.)
INTERMEDIATE SOLUTION (LI. BR.)
* REFRIGERANT (WATER)
CHILLED LIQUID
CONDENSER WATER
STEAM OR HOT WATER
*MILD SOLUTION AT LOW LOADS & LOW CONDENSING WATER TEMPERATURES EXCEPT WHERE SHADED.
70 mm Hg
1.346 PSIA
6 mm Hg
0.117 PSIA
38
CWS
CHILLED LIQUID
44
56
EVAPORATOR
95
85
CONDENSER WATER
ABSORBER
110
102
SOLUTION PUMP
REFRIGERANT PUMP

Figure 23. Absorber.

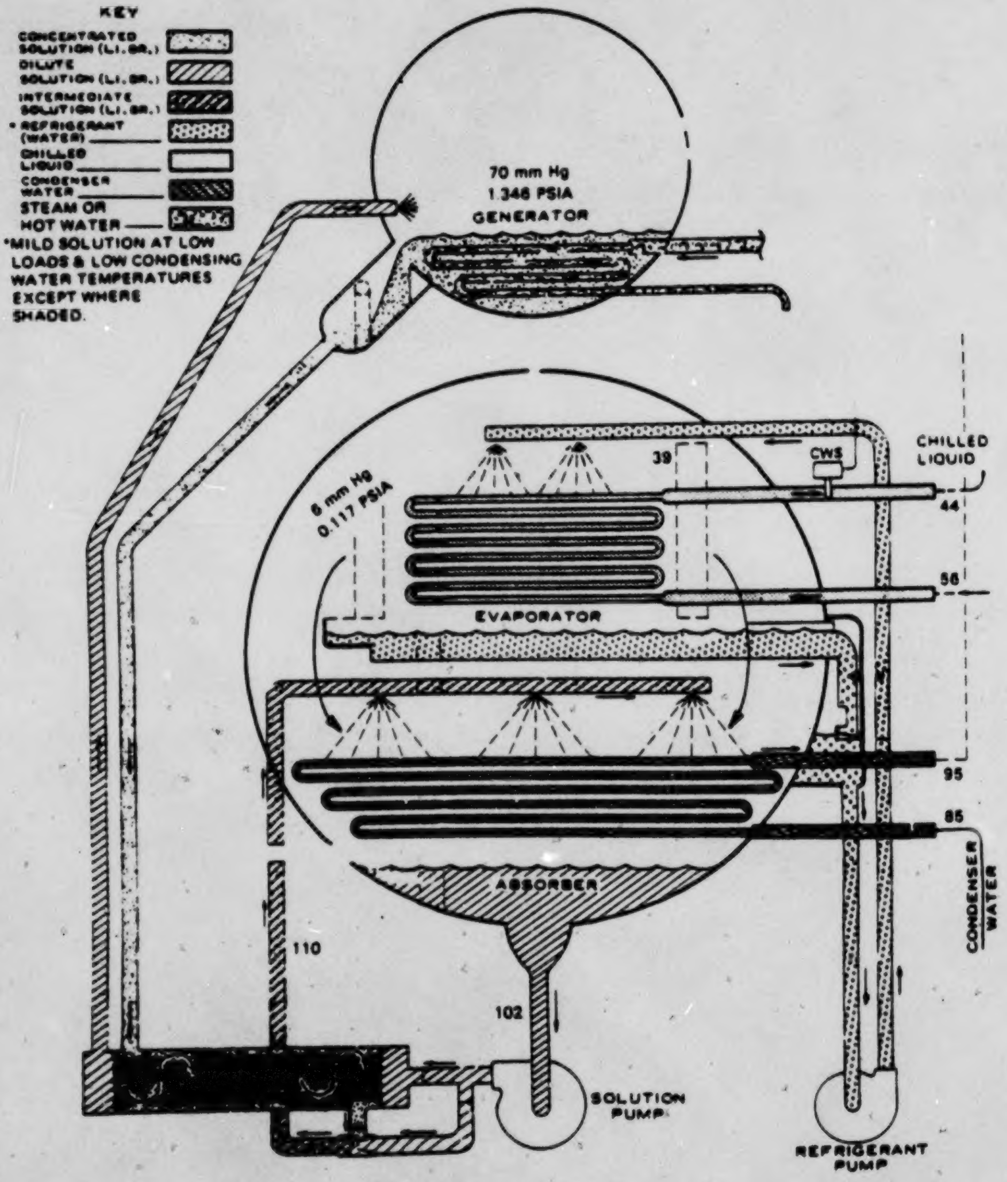

KEY
CONCENTRATED SOLUTION (LI. BR.)
DILUTE SOLUTION (LI. BR.)
INTERMEDIATE SOLUTION (LI. BR.)
*REFRIGERANT (WATER)
CHILLED LIQUID
CONDENSER WATER
STEAM OR HOT WATER
*MILD SOLUTION AT LOW LOADS & LOW CONDENSING WATER TEMPERATURES EXCEPT WHERE SHADED.
70 mm Hg
1.346 PSIA
GENERATOR
6 mm Hg
0.117 PSIA
39
CWS
CHILLED LIQUID
44
56
EVAPORATOR
95
85
CONDENSER WATER
ABSORBER
110
102
SOLUTION PUMP
REFRIGERANT PUMP

Figure 24. Generator.

CONDENSER

The condenser (Figure 25) is a water-cooled coil located in the shell with the generator. Water from the condenser coil of the absorber flows through the condenser and returns to the cooling tower. The water vapor from the generator condenses on the condenser coil and is returned to the evaporator in the lower shell.

HEAT EXCHANGER AND EDUCTOR

The efficiency of an absorption chiller is greatly increased by the addition of a heat exchanger (Figure 25). Hot concentrated LiBr solution from the generator flows through the heat exchanger in one direction and releases some of its heat to the solution traveling to the generator in the other direction. The eductor is a mixing device that mixes the concentrated LiBr solution from the generator with the weaker solution from the absorber. The resulting intermediate solution is sprayed on the coils of the absorber.

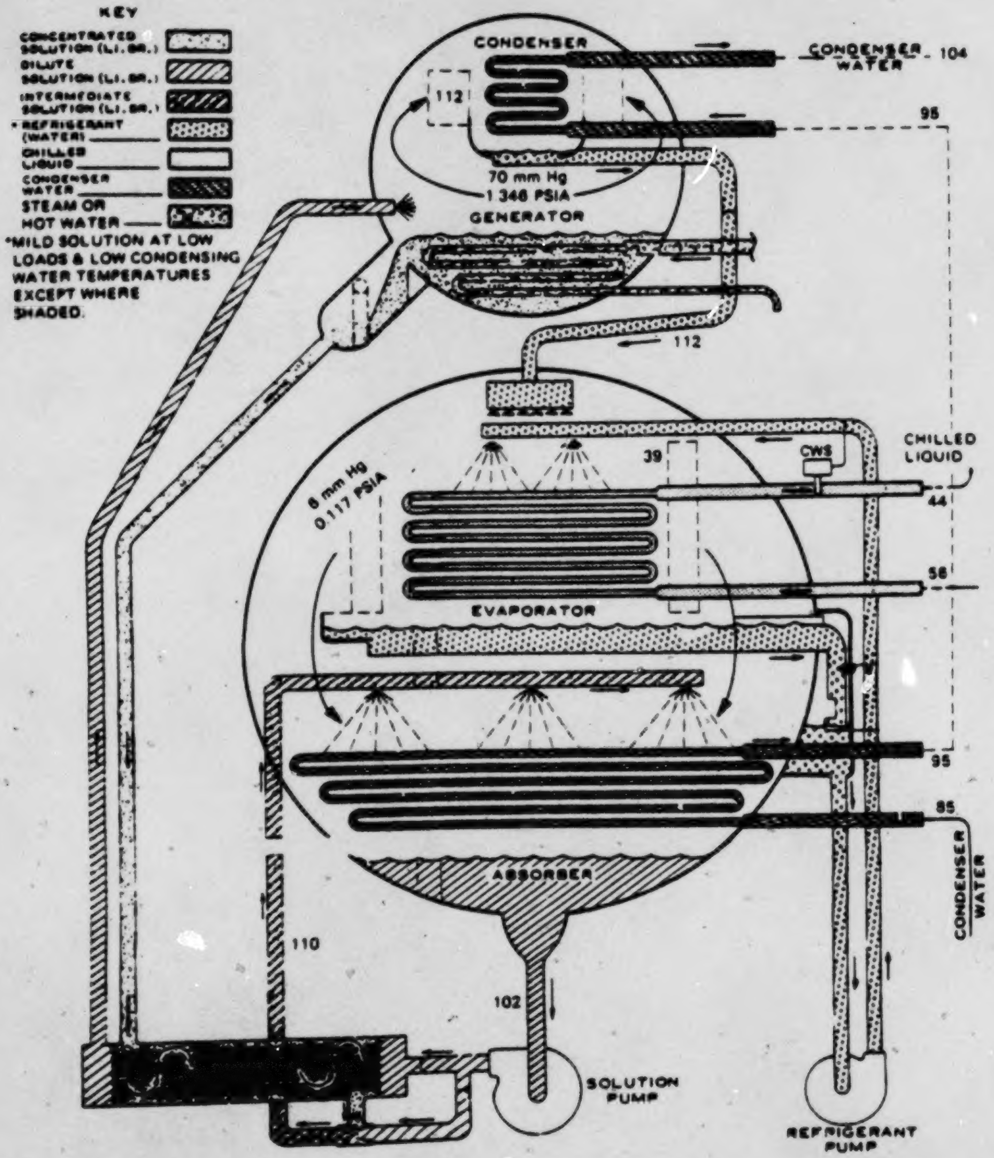

KEY
CONCENTRATED SOLUTION (LI. BR.)
DILUTE SOLUTION (LI. BR.)
INTERMEDIATE SOLUTION (LI. BR.)
*REFRIGERANT (WATER)
CHILLED LIQUID
CONDENSER WATER
STEAM OR HOT WATER
*MILD SOLUTION AT LOW LOADS & LOW CONDENSING WATER TEMPERATURES EXCEPT WHERE SHADED.
CONDENSER
CONDENSER WATER
104
112
95
70 mm Hg
1.346 PSIA
GENERATOR
112
CHILLED LIQUID
CWS
39
6 mm Hg
0.117 PSIA
44
56
EVAPORATOR
95
85
CONDENSER WATER
ABSORBER
110
102
SOLUTION PUMP
REFRIGERANT PUMP

Figure 25. Condenser.

Figure 26 shows a typical absorption liquid chiller. These units were very popular before rising energy costs made them uneconomical. Many absorption chillers are still in use in applications where hot water or steam is available as a by-product of some industrial process.

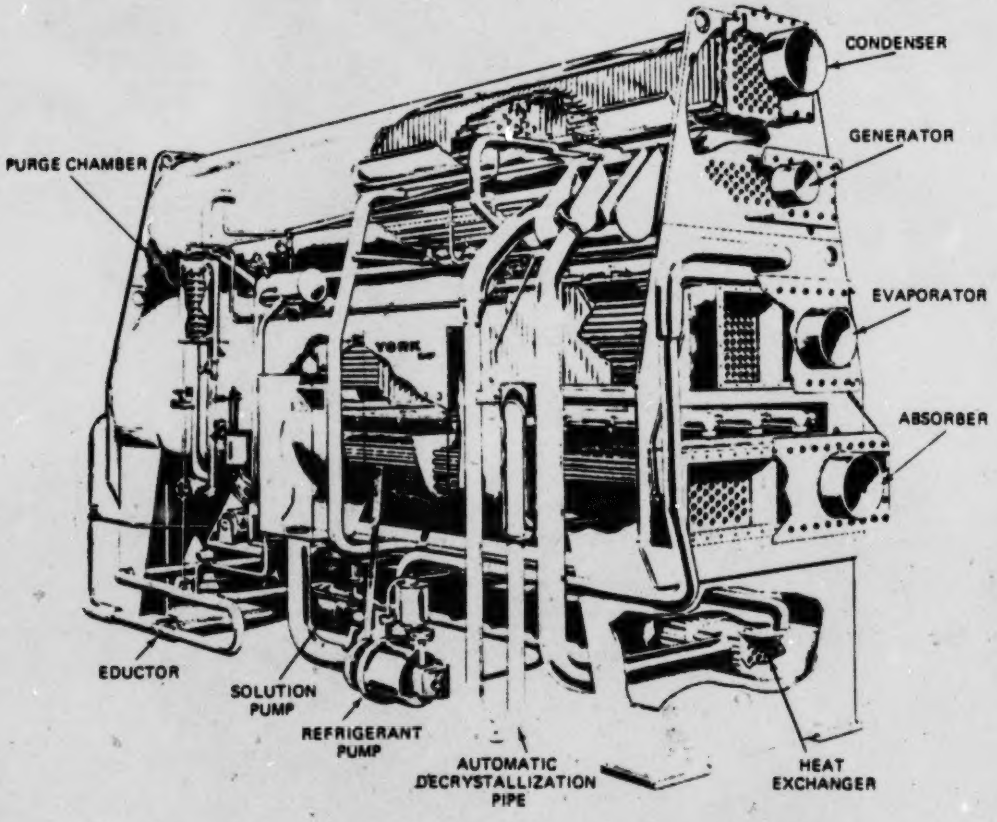

CONDENSER
GENERATOR
PURGE CHAMBER
EVAPORATOR
YORK
ABSORBER
EDUCTOR
SOLUTION PUMP
REFRIGERANT PUMP
AUTOMATIC DECRYSTALLIZATION PIPE
HEAT EXCHANGER

Figure 26. Absorption Liquid Chiller.

EXERCISES

1. Explain how each of the two major compressor types used in air conditioning systems compresses the refrigerant gas.
2. The equipment room of a large building is located in the basement, and the heat rejection equipment is on the roof. Explain the advantages and disadvantages of the following types of heat rejection equipment for this application and state which is the best choice:
   a. Air-cooled condenser.
   b. Evaporative condenser.
   c. Cooling tower.
3. Explain air flow in the following types of cooling tower:
   a. Counterflow, natural draft.
   b. Counterflow, draw through (induced draft).
   c. Cross flow, blow through (forced draft).
4. Explain the difference in the following types of water chillers:
   a. Dry expansion.
   b. Flooded.
5. Explain the difference in the operation of an automatic expansion valve and a thermostatic expansion valve.
6. Explain the purpose of the following system accessories.
   a. Oil separator.
   b. Muffler.
   c. Heat exchanger.
   d. Strainer drier.
7. Explain the operation of the control system of an air conditioner system using a thermostatic water valve at the fan coil, a thermostatic expansion valve, and a cylinder unloader that operates from suction line pressure.

8. Explain, with diagrams, the operation of an absorption chiller.

LABORATORY MATERIALS

Notebook or clipboard.
Pen or pencil.
Notes from lab in Module HC-02, "System Types."

LABORATORY PROCEDURES

This laboratory consists of the second of four field trips to a large central air conditioning installation. The system chosen should include a water chiller and cooling tower. The purpose of this visit is a detailed study of the refrigeration equipment.

1. Observe the system components during the refrigeration components familiarization tour. Record in the field notebook the data specified in the Data Table and any other information available concerning the system.
2. Sketch the following components in the field notebook:
   a. Oil separator.
   b. Muffler.
   c. Heat exchanger.
   d. Strainer-drier.
   e. Sight glass.
   f. Water pumps.
   g. Water control valves.
   h. Refrigerant control valves.

3. Draw a diagram showing the components, water flow, and air flow of the cooling tower.
4. Draw circuit diagrams showing all components and connecting pipes for the following heat exchanging loops:
   a. Refrigerant.
   b. Chilled water.
   c. Condensing water.
5. Explain all system controls.
6. Calculate the system capacity in tons of refrigeration effect, using the following equation:

$$C = \frac{1}{24} V\Delta T$$

where:

C = Capacity in tons.
V = Water flow rate through chiller in gal/min.
ΔT = Change in water temperature in chiller in °F.

7. Determine the volume of water evaporated per hour in the cooling tower (1.8 gal/hr per ton).
8. After the field trip, draw a single schematic diagram showing all components of the refrigeration system.

DATA TABLE

DATA TABLE

COMPRESSOR

Type: ____________________
Drive: ____________________
Maximum drive power (kw and hp): ____________________
Capacity control: ____________________
Refrigerant: ____________________
Suction line pressure: ____________________
Discharge pressure: ____________________

CONDENSER

Type: ____________________
Inlet water temperature: ____________________
Outlet water temperature: ____________________
Water flow rate: ____________________

COOLING TOWER

Type: ____________________
Cooling range: ____________________
Approach: ____________________
Ambient wet bulb temperature: ____________________
Entering wet bulb temperature: ____________________

CHILLER

Type: ____________________
Inlet water temperature: ____________________
Outlet water temperature: ____________________
Water flow rate: ____________________
Cooling capacity (tons): ____________________
Water evaporated (gal/hr): ____________________

REFERENCES

Air Conditioning and Refrigeration Institute. Refrigeration and Air-Conditioning. Englewood Cliffs, NJ: Prentice-Hall, Inc., 1979.

Althouse, Andrew D.; Turnquist, Carl H.; and Bracciano, Alfred F. Modern Refrigeration and Air Conditioning. Homewood, IL: The Goodheart-Willcox Company, Inc., 1979.

Carrier Air Conditioning Company. Handbook of Air Conditioning System Design. NY: McGraw-Hill Book Co., 1965.

TPC Training Systems. Condensers and Cooling Towers. Barrington, IL: Technical Publishing Co., 1977.

TEST

1. Centrifugal compressors...
   - a. are often driven by steam turbines.
   - b. may have adjustable gas inlet vanes for capacity control.
   - c. are the most common compressor type in systems of 125 tons or greater.
   - d. All of the above.
2. Which of the following methods of compressor capacity control has the poorest energy efficiency?
   - a. Cylinder unloading.
   - b. Compressor drive speed control.
   - c. On-off control of compressor drive.
   - d. Hot gas bypass.
   - e. Adjustable inlet vanes.
3. Which of the following heat rejection devices is lower in first costs and has lowest maintenance costs?
   - a. Air-cooled condensers.
   - b. Evaporative condensers.
   - c. Cooling towers.
   - d. Water-cooled condensers.
4. Which of the following is not a disadvantage of air-cooled condensers?
   - a. Capacity decreases as wet bulb temperature rises.
   - b. Large volumes of air are required.
   - c. Possible noise problems.
   - d. Capacity decreases as dry bulb temperature rises.
5. The capacity of a water-cooled condenser is dependent upon...
   - a. temperature of entering water.
   - b. water flow rate.

- c. temperature of entering refrigerant gas.
- d. All of the above.

6. A cooling tower has a fan that forces air into one side of the tower. The air flows out through the other side. This tower is a...
   - a. counter flow, natural draft.
   - b. counter flow, induced draft.
   - c. cross flow, forced draft.
   - d. cross flow, induced draft.
7. Which of the following is true of cooling towers?
   - a. They require more space than air cooled condensers or evaporative condensers.
   - b. Their capacity decreases as the dry bulb temperature rises.
   - c. Long piping runs often cause problems.
   - d. Maintenance requirements cause them to be used only infrequently.
   - e. None of the above.
8. Which of the following is not true of evaporative condensers?
   - a. They consist of a single unit incorporating the features of a water-cooled condenser and a cooling tower.
   - b. Their capacity increases as the wet bulb temperature drops.
   - c. They are often located inside the equipment room, and outside air is supplied and exhausted by ducts.
   - d. They are more popular than cooling towers for remote cooling because they eliminate the need for long runs of water pipes.
   - e. None of the above (all are true).

9. Which of the following is not a common evaporator type in air conditioner systems?
   a. Dry expansion coils that directly cool the air forced across them.
   b. Flooded expansion coils that directly cool the air forced across them.
   c. Dry expansion water chillers in which tubes carry refrigerant through a water filled cylinder.
   d. Flooded water chillers in which pipes carry water through a cylinder filled with liquid refrigerant.
   e. None of the above (all are in common use).
10. Which type of metering device monitors suction line temperature?
    a. Automatic expansion valve.
    b. Thermostatic expansion valve.
    c. High side float.
    d. Low side float.
11. In an air conditioning system using a thermostatic expansion valve the compressor capacity is usually controlled by...
    a. suction line temperature.
    b. fan coil water temperature.
    c. suction line pressure.
    d. compressor discharge pressure.
12. The refrigerant in an absorption chiller is usually...
    a. LiBr.
    b. R-12.
    c. R-22.
    d. water.

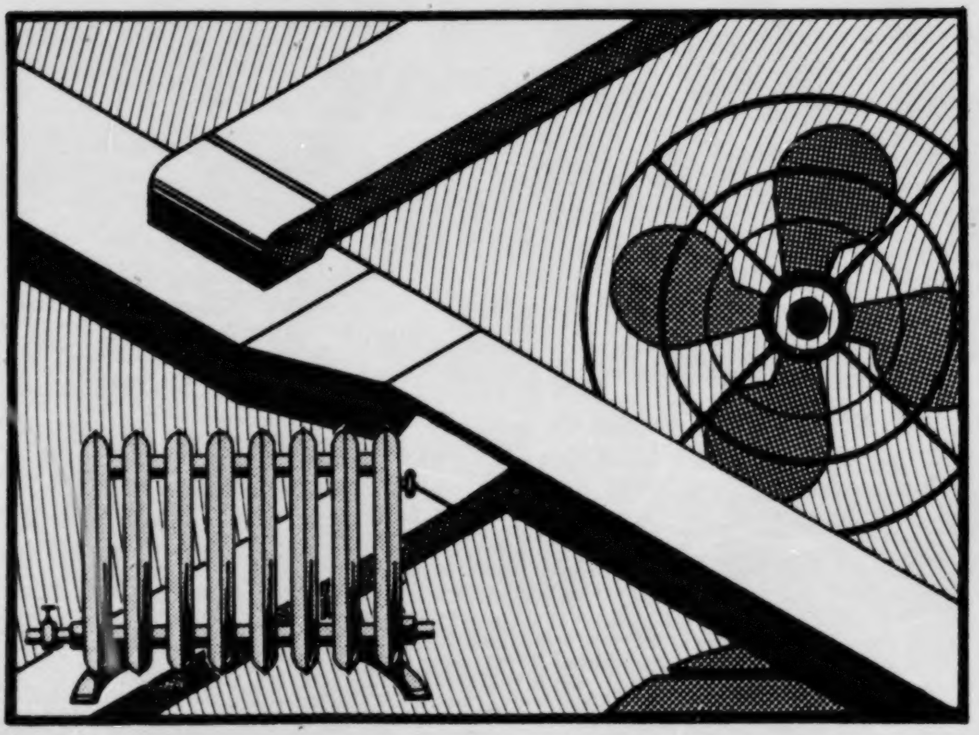
13. The major component of an absorption unit that cools the "chilled water" for the fan coil is called the...
    a. evaporator.
    b. generator.
    c. absorber.
    d. condenser.
    e. heat exchanger.

14. Absorption chillers...
    a. have found more widespread use as energy costs have risen.
    b. require steam for their operation.
    c. are usually employed in situations in which waste energy is available in the form of steam or hot water.
    d. do not require cooling towers.

ENERGY TECHNOLOGY

CONSERVATION AND USE

HEATING, VENTILATING, AND AIR CONDITIONING



MODULE HC - 04

RESIDENTIAL HEATING EQUIPMENT

CORD CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

INTRODUCTION

Residential heating equipment may use electrical heat or the combustion heat of fuel oil or natural gas. All three types of warm air furnaces are in common use. The one selected for a particular application depends upon the availability and cost of fuel and electricity at the unit location.

This module discusses the basic configurations of warm air furnaces and their applications. The components and operation of electric, oil-fired, and gas-fired furnaces are presented. Maintenance and adjustment instructions for gas-fired warm air furnaces are included and are used by the student in a practical laboratory exercise in furnace maintenance.

PREREQUISITES

The student should have completed Module HC-02, "System Types."

OBJECTIVES

Upon completion of this module, the student should be able to:

1. List the four basic warm air furnace configurations and state the application of each.
2. State the three major advantages of electric furnaces.
3. Draw and label a diagram of a Klixon limit control and explain its operation.

4. Given a diagram of an oil-fired furnace, identify the following components:
    a. Supply air duct.
    b. Return air duct.
    c. Flue outlet.
    d. Filter.
    e. Blower.
    f. Blower motor.
    g. Oil burner.
    h. Combustion chamber.
    i. Heat exchanger.
    j. Jacket.
5. Explain the operation of the following components of an oil burner:
    a. Air adjustment.
    b. Deflector vanes on air tube.
    c. Ignition system.
    d. Oil pump and nozzle.
    e. Flame detector.
6. Explain the difference between an oil combustion chamber and a gas combustion chamber.
7. Explain, with the use of a diagram, how primary and secondary air are provided in a gas burner.
8. Describe the main burner flame if the primary air shutter is as follows:
    a. Opened too far.
    b. Closed down too far.
    c. Adjusted properly.
9. Explain the operation of the thermocouple and the valve it controls.
10. Explain, with the use of diagrams, the operation of the gas valve of a gas-fired furnace.

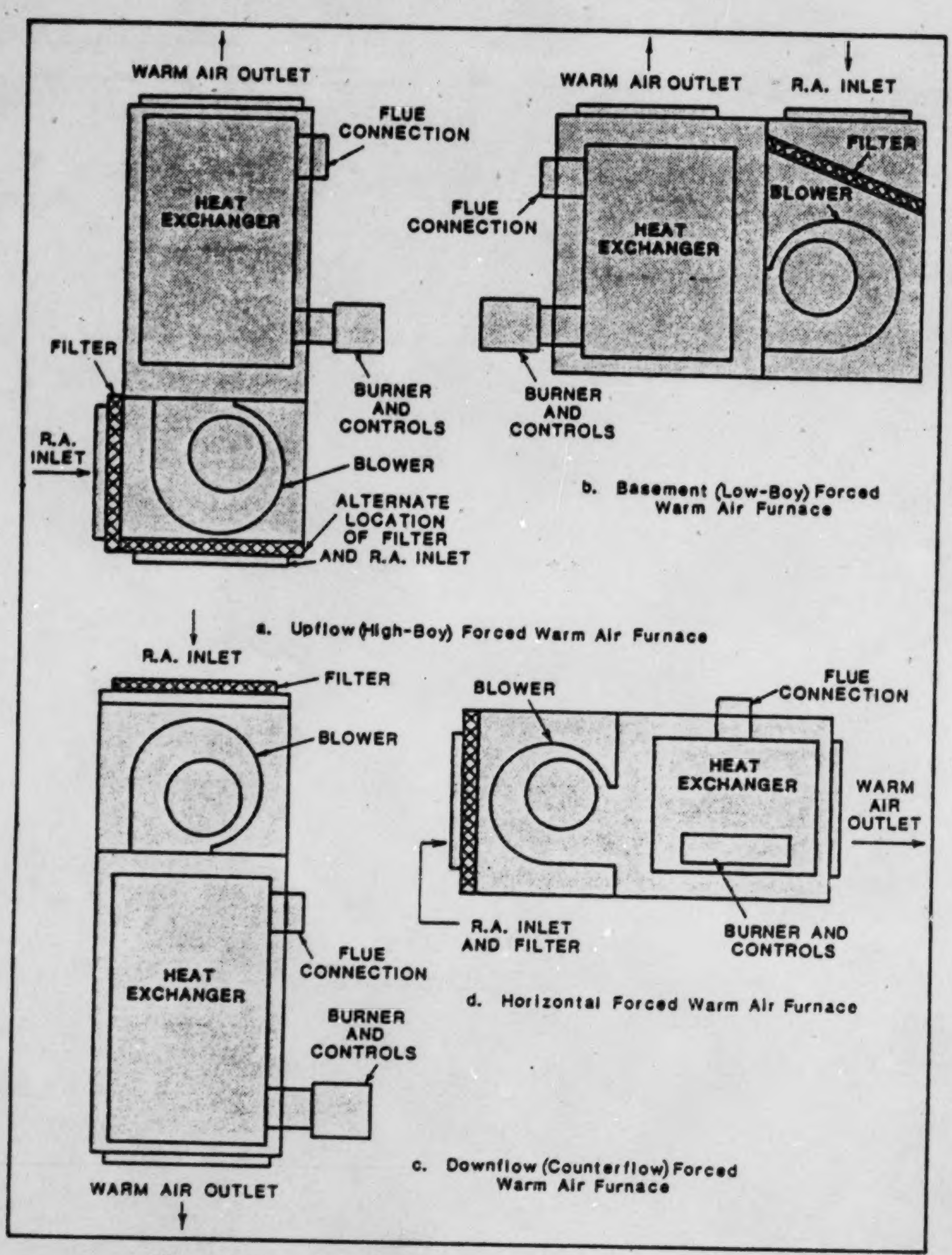
11. Explain the following test procedures for a gas-fired furnace:
    a. Test heat exchanger for leaks.
    b. Test thermocouple output.
    c. Check dropout time of thermocouple-controlled valve.
    d. Check primary air adjustment.
    e. Check gas manifold pressure.
12. Check, adjust, and operate a gas-fired furnace in the laboratory.

WARM AIR FURNACES

Most residential heating is provided by warm air furnaces that burn fuel oil or natural gas or incorporate electrical heating elements. Air circulation may result from convection currents, but a blower is usually employed. The warmed air is usually delivered to the heated space by a system of ducts. Four basic configurations of warm air furnaces and their applications are discussed in the following paragraphs.. Each type may also incorporate an evaporator coil to provide air conditioning service.

UPFLOW FORCED WARM AIR FURNACE

In the upflow, or "high-boy," furnace (Figure 1a) air enters through a filter at the bottom of the cabinet and is blown upward through the heat exchanger. This furnace configuration is widely used in utility rooms located on the first floor of homes without basements and in basements with return air ducts leading to the blower compartment. The primary advantages of this furnace design are the small floor space required and the use of overhead or attic delivery ducts.


WARM AIR OUTLET
FLUE CONNECTION
HEAT EXCHANGER
FILTER
BURNER AND CONTROLS
R.A. INLET
BLOWER
ALTERNATE LOCATION OF FILTER AND R.A. INLET
WARM AIR OUTLET
R.A. INLET
FILTER
BLOWER
FLUE CONNECTION
HEAT EXCHANGER
BURNER AND CONTROLS
R.A. INLET
FILTER
BLOWER
FLUE CONNECTION
HEAT EXCHANGER
BURNER AND CONTROLS
WARM AIR OUTLET
BLOWER
FLUE CONNECTION
HEAT EXCHANGER
WARM AIR OUTLET
R.A. INLET AND FILTER
BURNER AND CONTROLS

a. Upflow (High-Boy) Forced Warm Air Furnace

b. Basement (Low-Boy) Forced Warm Air Furnace

c. Downflow (Counterflow) Forced Warm Air Furnace

d. Horizontal Forced Warm Air Furnace

Figure 1. Warm Air Furnace Configurations.

BASEMENT FORCED WARM AIR FURNACE

As the name implies, the basement forced warm air furnace (Figure 1b) is primarily designed for basement installation. It requires more floor space but less head room. The low-boy, a modification of the high-boy, is classified as an upflow furnace.

DOWNFLOW FORCED WARM AIR FURANCE

The downflow, or "counter-flow," furnace (Figure 1c) is designed to intake return air at the top of the cabinet and exhaust warm air at the bottom. This furnace design is used for perimeter heating of houses without basements and in mobile homes. It requires little floor space and is best suited for use with a delivery duct system under the floor.

HORIZONTAL FORCED WARM AIR FURNACE

The horizontal flow furnace (Figure 1d) moves air through the cabinet in a horizontal direction. Such units are used in locations with limited head room such as in attics, in crawl spaces, below floors, and above suspended ceilings.

ELECTRIC FURNACES

HEATING ELEMENT

The heating element of an electric furnace (Figure 2) consists of a wound element of nichrome wire looped around a rack on ceramic insulators. Most residential electric furnaces use 20-gauge wire and operate on 220-V a.c. current. One of the advantages of electric heating is the small space requirement for the electric element. Heat exchange occurs as air passes across the element. Another advantage of electric heat is the absence of an exhaust system for combustion gases.

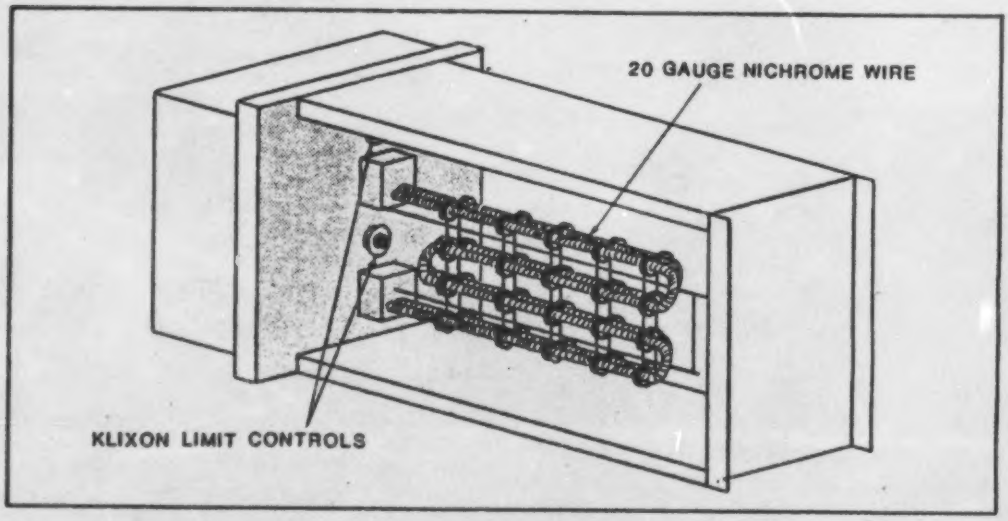


Figure 2. Heating Element of Electric Furnace.

LIMIT CONTROLS

A third major advantage of the electric furnace is the ease of control. The klixon-type element shown in Figure 3 is incorporated in each heating element and switches that element OFF if the switch temperature exceeds 170°F. Similar switches are used to control fan operation in this and other warm air furnaces. They switch the fan ON after the furnace has heated to operating temperature and turn it OFF after the furnace has cooled.

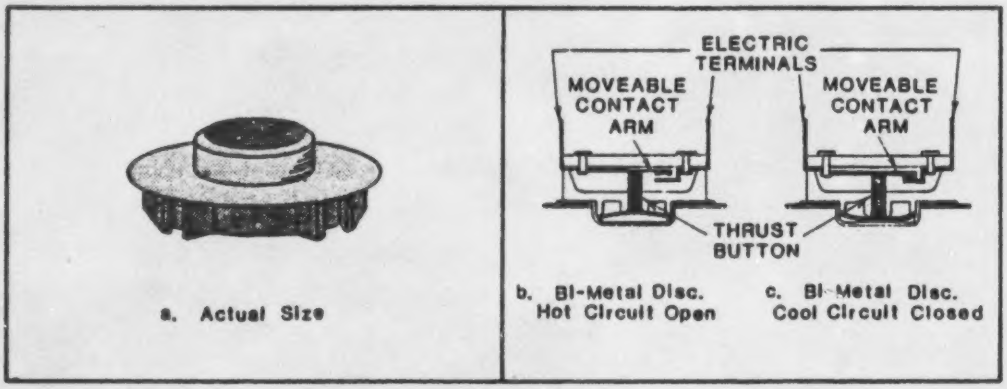

ELECTRIC TERMINALS
MOVEABLE CONTACT ARM
MOVEABLE CONTACT ARM
THRUST BUTTON
a. Actual Size
b. Bi-Metal Disc. Hot Circuit Open
c. Bi-Metal Disc. Cool Circuit Closed

Figure 3. Klixon-Type Limit Control.

OIL-FIRED FURNACES

Figure 4 shows the components of a typical oil-fired furnace (low-boy design). The principal parts of this furnace are the combustion chamber, heat exchanger, and oil burner.

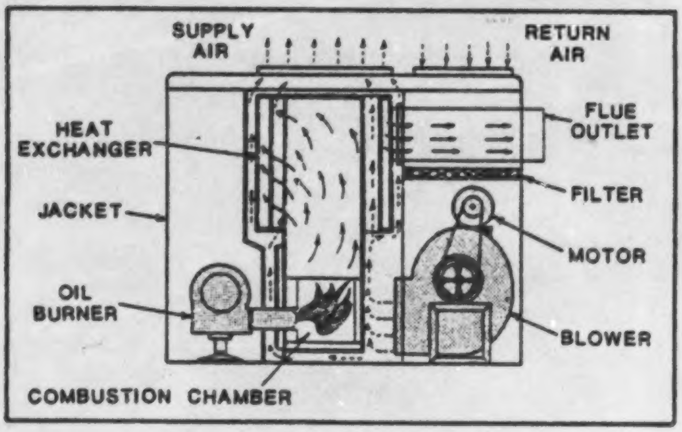

SUPPLY AIR
RETURN AIR
HEAT EXCHANGER
FLUE OUTLET
JACKET
FILTER
MOTOR
OIL BURNER
BLOWER
COMBUSTION CHAMBER

Figure 4. Typical Oil-Fired Furnace.

COMBUSTION CHAMBER

The combustion chamber of an oil furnace must reach a high temperature quickly and maintain that temperature for complete combustion of the oil. The lining of the chamber (Figure 5) is made of lightweight refractory material that assures proper combustion temperature and protects the metal walls from that temperature.

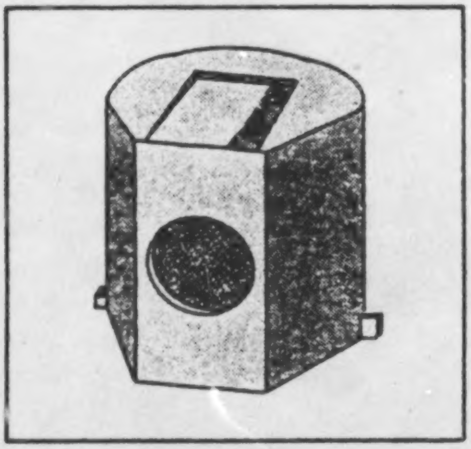


Figure 5. Refractory Used in the Combustion Chamber.

HEAT EXCHANGER

The hot gases from the combustion chamber pass through a metal heat exchanger where their thermal energy is transmitted through the walls to the air to be heated. As much as 80% of the thermal energy is transferred to the heated air. Figure 6 shows several oil heat exchangers.

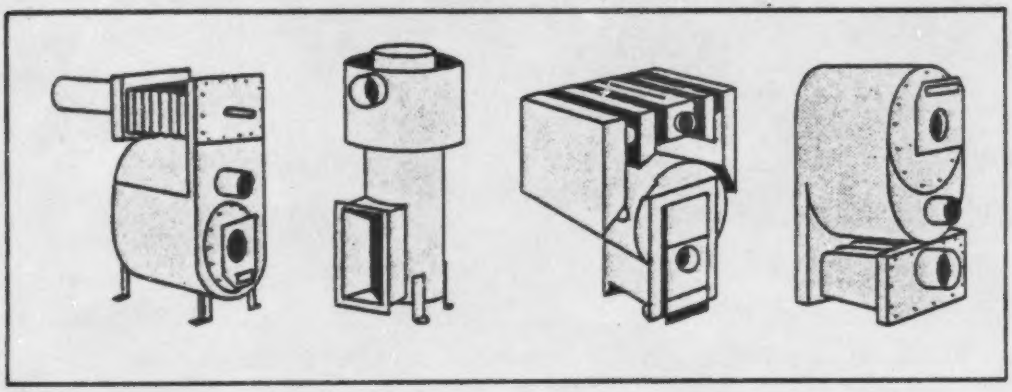


Figure 6. Typical Oil Heat Exchangers.

ATOMIZING OIL BURNER

Most residential oil-fired furnaces (over 95%) employ the high-pressure atomizing oil burner shown in Figure 7. This unit consists of a fan, oil pump, oil nozzle, ignition system, and flame detector.

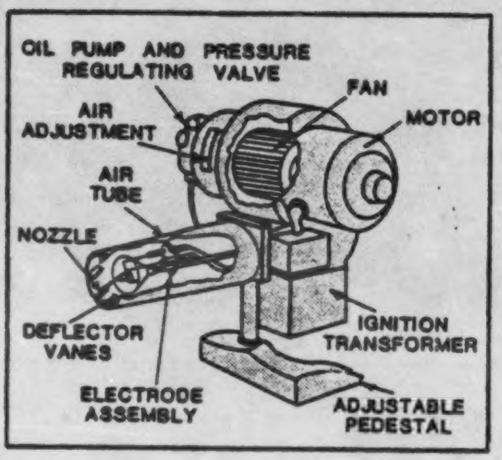

OIL PUMP AND PRESSURE REGULATING VALVE
FAN
MOTOR
AIR ADJUSTMENT
AIR TUBE
NOZZLE
DEFLECTOR VANES
ELECTRODE ASSEMBLY
IGNITION TRANSFORMER
ADJUSTABLE PEDESTAL

Figure 7. High-Pressure Atomizing Oil Burner.

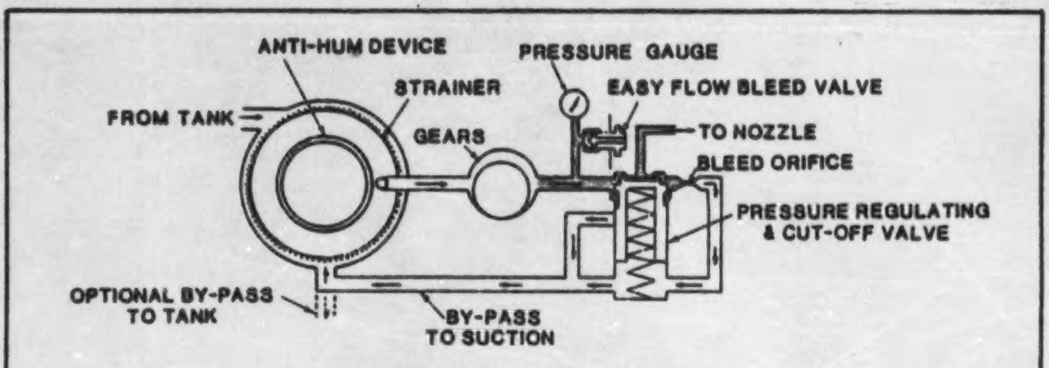
Fan and Combustion Air Adjustment

Combustion air for the oil fire is supplied by a fan internal to the burner. The amount of air provided is controlled by adjustable openings on the fan intake (Figure 7).

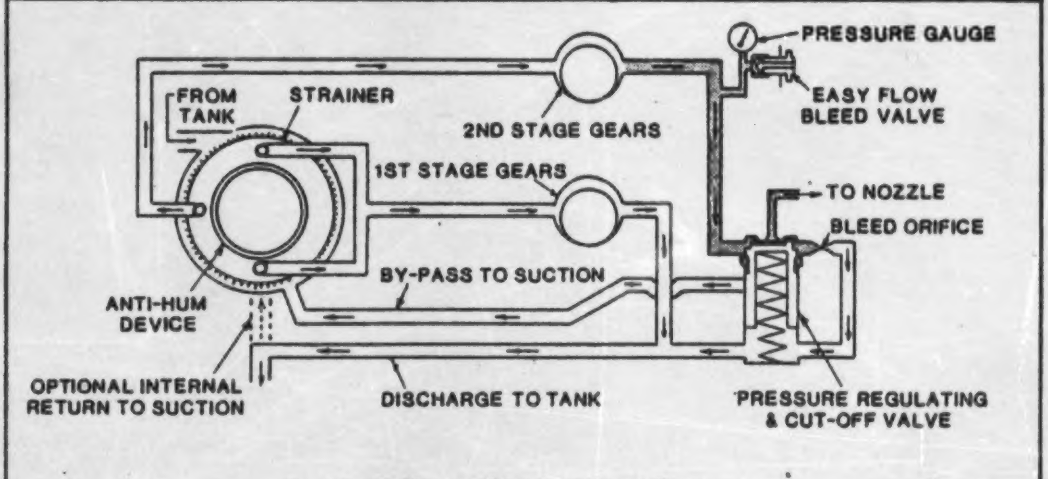
Oil Pump

Figure 8 shows the oil circuit diagrams of two types of oil pumps commonly incorporated in residential oil burners. Both employ a recirculating system in which regulation is accomplished by controlling the amount of oil that bypasses the nozzle.

The single-stage pump (Figure 8a) is used in gravity-fed and low-lift (less than 10 in Hg vacuum) applications. The two-stage pump (Figure 8b) has two sets of pump gears. The first stage lists oil to the pump and the second stage provides pressurized oil to the nozzle. The oil delivery pressure is typically 100-300 psi.


ANTI-HUM DEVICE
PRESSURE GAUGE
STRAINER
EASY FLOW BLEED VALVE
FROM TANK
GEARS
TO NOZZLE
BLEED ORIFICE
PRESSURE REGULATING & CUT-OFF VALVE
OPTIONAL BY-PASS TO TANK
BY-PASS TO SUCTION

a. Circuit Diagram Of A Single-Stage Pump

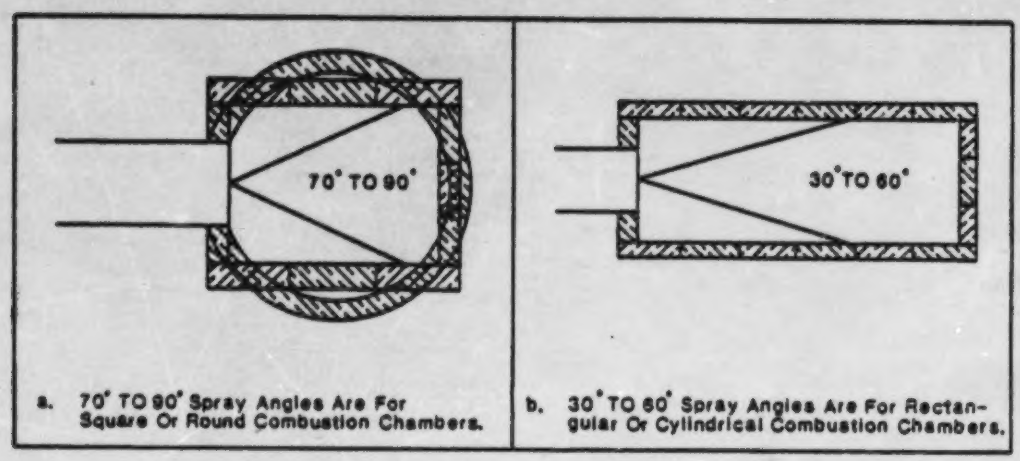

PRESSURE GAUGE
FROM TANK
STRAINER
EASY FLOW BLEED VALVE
2ND STAGE GEARS
1ST STAGE GEARS
TO NOZZLE
BLEED ORIFICE
BY-PASS TO SUCTION
ANTI-HUM DEVICE
OPTIONAL INTERNAL RETURN TO SUCTION
DISCHARGE TO TANK
PRESSURE REGULATING & CUT-OFF VALVE

b. Circuit Diagram Of A Two-Stage Pump

Figure 8. Oil Pumps.

Oil Nozzle

The oil nozzle is designed to provide a conical spray of oil that matches the shape of the combustion chamber, as shown in Figure 9. Deflector vanes (Figure 7) cause the air and fuel mixture to spin as it leaves the end of the burner. This mixes the air and fuel and provides for complete combustion.



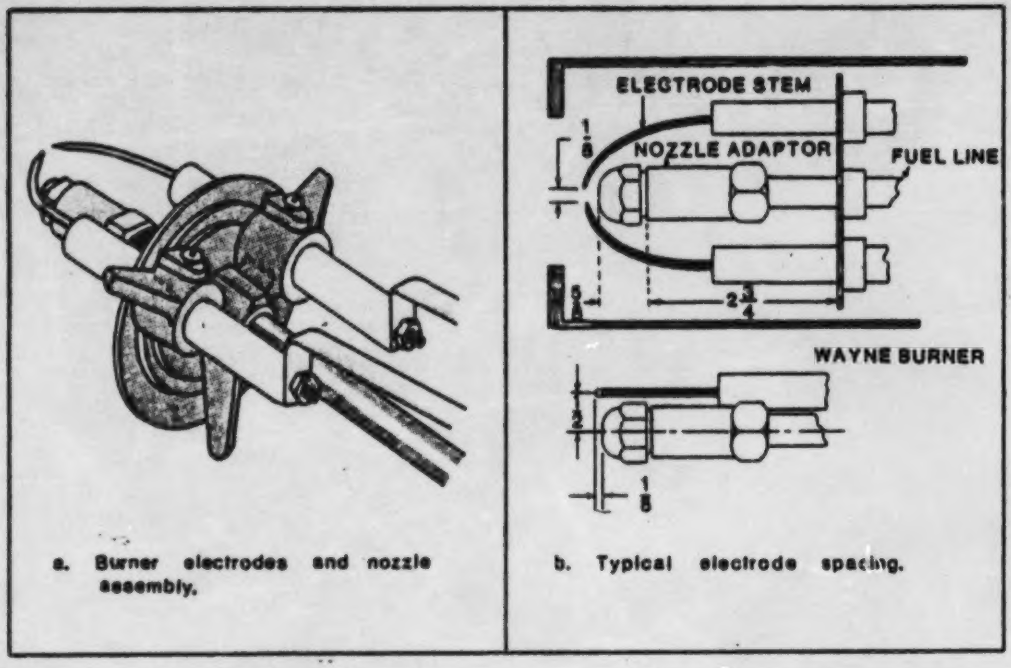
a. 70° TO 90° Spray Angles Are For Square Or Round Combustion Chambers.

b. 30° TO 60° Spray Angles Are For Rectangular Or Cylindrical Combustion Chambers.

Figure 9. Oil Spray Shapes.

Ignition System

Figure 10 shows the ignition electrodes of a typical oil burner. An a.c. voltage of about 10,000 V is applied across the electrodes by the ignition transformer (Figure 7). The transformer limits arc current to about 23 mA. Some systems produce an arc only during initial ignition of the oil flame, but most employ continuous ignition. This means that the arc is present anytime the burner is operating and will assure that the flame remains lighted as long as fuel is present.



a. Burner electrodes and nozzle assembly.

b. Typical electrode spacing.

Figure 10. Ignition Electrodes of an Oil Burner.

Flame Detector

If the ignition system fails, or if the flame is extinguished and not relighted immediately, a dangerously explosive mixture of fuel and air fills the combustion chamber and heat exchanger. A cadmium sulfide cell is positioned inside the burner, as shown in Figure 11. This photoconductive element has a high resistance (100,000 Ω) in darkness, but its resistance falls in the presence of visible light (300-1000 Ω). It is positioned so light from the oil flame falls on the cell. As long as a flame is "seen," the burner operates. If the light from the flame ceases to strike the cell, it turns OFF the oil spray and burner motor. For proper operation the cell must receive light directly from the flame, and no outside light should enter the combustion chamber.

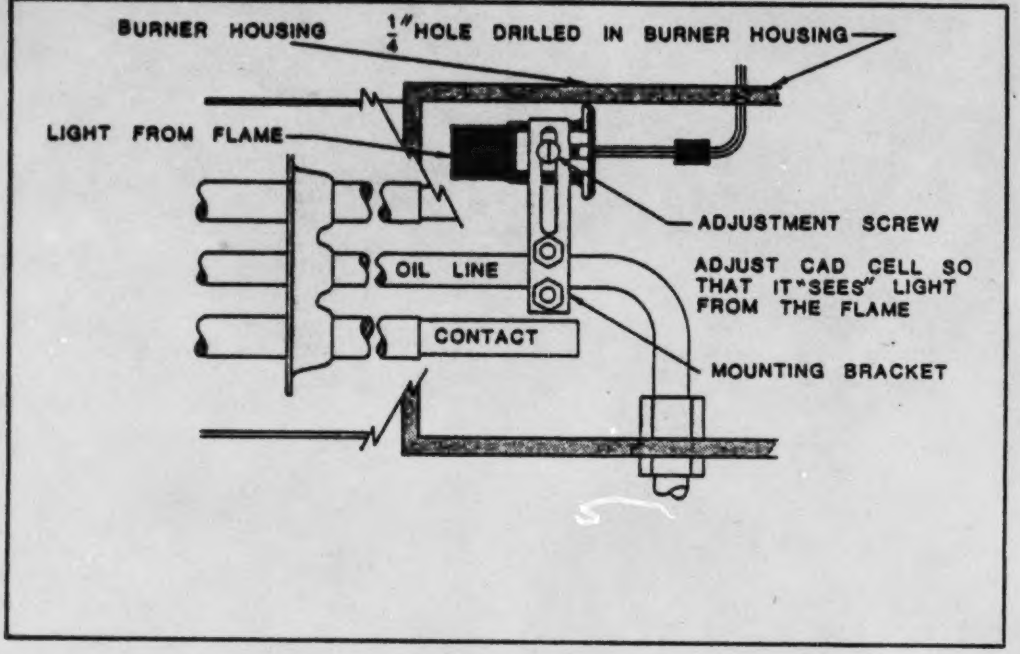

BURNER HOUSING
$\frac{1}{4}$" HOLE DRILLED IN BURNER HOUSING
LIGHT FROM FLAME
ADJUSTMENT SCREW
OIL LINE
ADJUST CAD CELL SO THAT IT "SEES" LIGHT FROM THE FLAME
CONTACT
MOUNTING BRACKET

Figure 11. Mounting the Cad Cell.

GAS-FIRED FURNACES

HEAT EXCHANGER

The heat exchanger of a gas-fired furnace is often called a "clamshell" because it is made of two pieces of metal stamped into right and left halves and welded together. Several clamshell designs are shown in Figure 12. The heat exchanger of a gas furnace is usually composed of several clamshells, as shown in Figure 13.

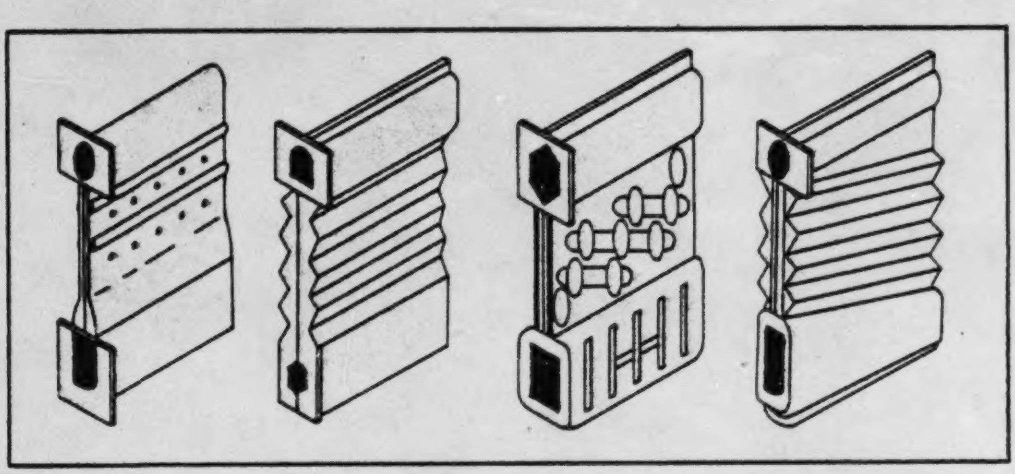


Figure 12. Typical Clamshell Heat Exchanger Designs.

The large opening at the bottom of the heat exchanger is the combustion chamber, which contains the gas burners. The chamber temperature for gas fires is much lower than for oil fires, and no refractory material is needed. The hot combustion gases rise through the inside of the clamshell and are exhausted through the ports at the top. About 80% of the heat is transferred to the air blown across the outside of the clamshells. The surface area of the exchanger is increased by using the shapes shown in Figure 12.

Leaks in the heat exchanger may be detected by spraying a solution of table salt and water into the combustion chamber during furnace operation. A butane torch is then positioned in the warm output air from the heat exchanger. If

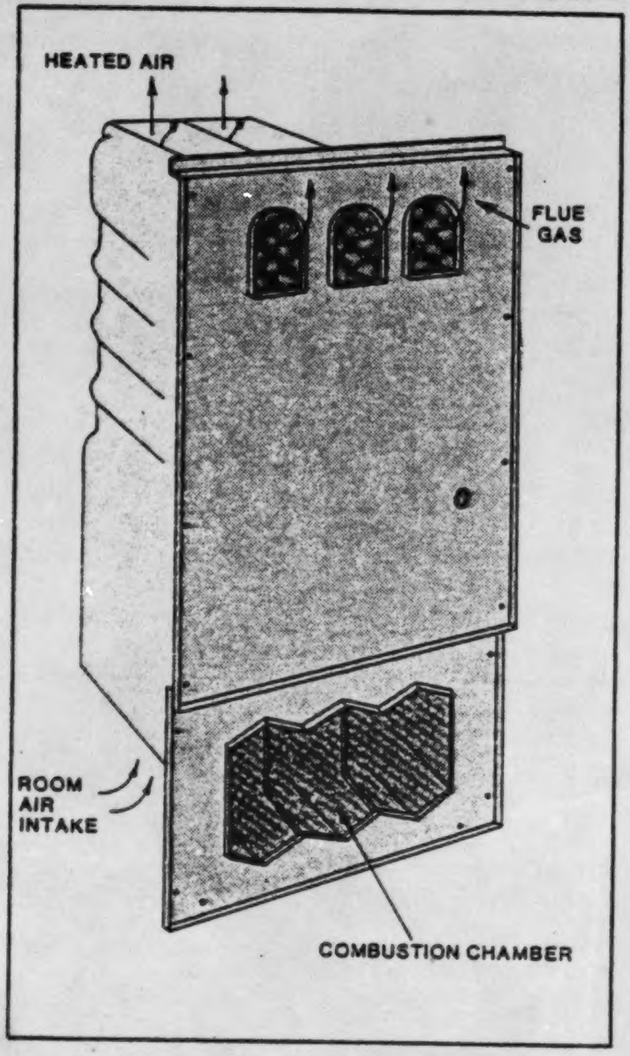


Figure 13. Heat Exchanger Composed of Three Clamshells.

any of the salt solution has mixed with the heated air (indicating a leak in the heat exchanger), the butane flame will change color from blue to yellow.

MAIN GAS BURNERS

The principle of operation of a gas burner is illustrated in Figure 14. Gas under a small positive pressure sprays through an orifice into the throat of the burner. Primary combustion air is drawn into the burner throat by venturi action. This air and gas mixture flows upward through holes in the burner. Combustion takes place above the burner surface. Secondary air inside the combustion chamber provides for complete combustion of the gas. Figure 15 shows four common burner configurations.

Gas burners for residential use do not employ combustion air blowers. Air is moved through the gas furnace by convection. The heated air rises through the heat exchanger and exhaust system, and room air is drawn into the combustion chamber.

Combustion is controlled by adjusting the ratio of primary air to gas with a primary air shutter located around the gas orifice at the rear of the burner (Figure 16). If too little primary air is admitted, the flame will be tall and will have yellow tips due to the incomplete combustion of carbon. If the primary air supply is set too high, the flame may roar and be blown upward away from the surface of the burner. When a burner with too much primary air is turned OFF (by closing the gas supply valve), the unburned fuel-

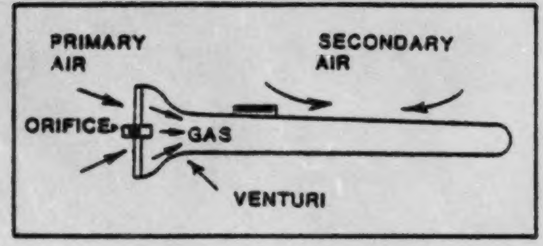


Figure 14. Supplying Primary and Secondary Air to Burner.

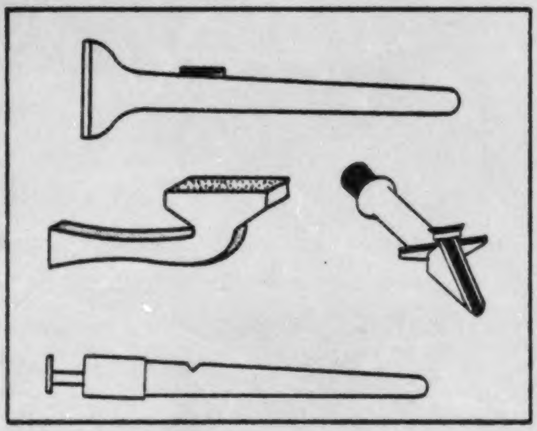


Figure 15. Several Burner Designs.

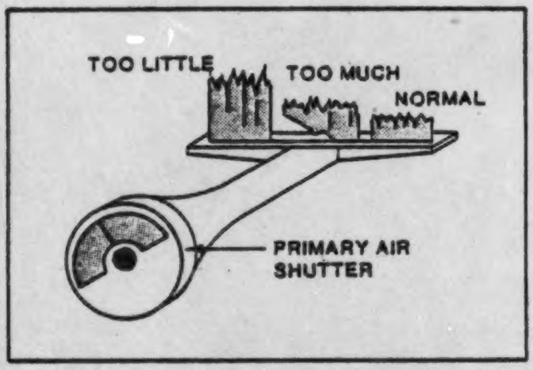


Figure 16. Effects of Poor Adjustment of Primary Air.

air mixture inside the burner ignites to produce a loud popping or extinction noise, and the pilot flame may be blown out.

The primary air supply is adjusted by lighting the burner and closing the primary air shutter until the tip of the flame is yellow. The air shutter is then opened until the yellow disappears, and a locking screw is tightened to hold the shutter at the proper setting.

PILOT BURNERS

The main burners of gas-fired furnaces are ignited from small pilot flames that burn continuously. Figure 17 shows the typical shape of a normal pilot flame. The flame is flared in two directions. One side of the flame strikes the thermocouple control element (described later in this module), and the other side is directed toward the main burner for ignition.

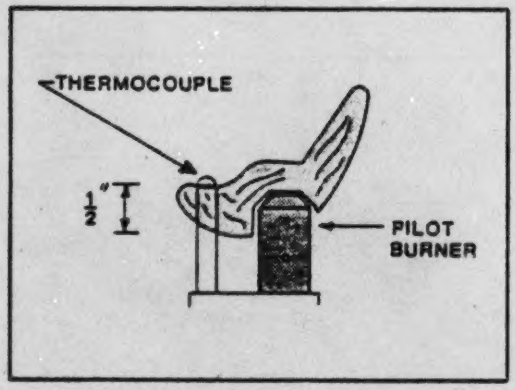


Figure 17. Normal Pilot Flame Fans Out in Two Directions.

The size of the pilot flame is adjusted by the pilot adjust screw on the gas valve (Figure 22). The pilot flame should be adjusted so approximately one-half inch of the thermocouple rod is in contact with the flame.

Primary air for the pilot flame is provided by a slot or a drilled hole in the pilot burner. A yellow pilot flame indicates that the primary air hole is blocked.

THERMOCOUPLE

The flame-sensing element of a gas furnace is a thermocouple heated by the pilot flame. The voltage produced by the thermocouple drives a low voltage coil in the gas valve. If the pilot flame goes out, the coil is de-energized, and the valve closes. This provides 100% safety shutoff, and it does not depend on any external electric power.

The thermocouple may be tested by inserting a General controls adapter No. 103050G between the thermocouple lead and the gas valve. The voltage between the outer conductor of the thermocouple lead and the side terminal of the adapter (Figure 18) is measured with a d.c. millivoltmeter. A voltage of at least 7 mV is required to operate the gas valve. If the reading is below 7 mV, the pilot burner should be cleaned or repositioned, or the pilot

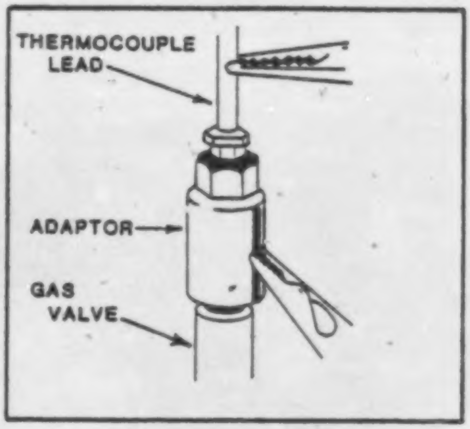


Figure 18. Connecting Millivoltmeter Probes to Adapter.

flame size should be increased. If this does not increase the voltage to 7 mV or greater, the thermocouple should be replaced.

GAS VALVE

The most common gas valve for gas-fired furnaces includes a pressure regulator, pilot flame adjustment, pilot valve, and main gas valve. Figures 19 through 22 illustrate the normal operation of the gas valve.

In Figure 19 the gas valve is in the OFF position. There is no pilot flame, so the thermocouple-controlled valve is closed. The main valve also is closed to prevent the escape of any gas that may leak past the thermocouple-controlled valve.

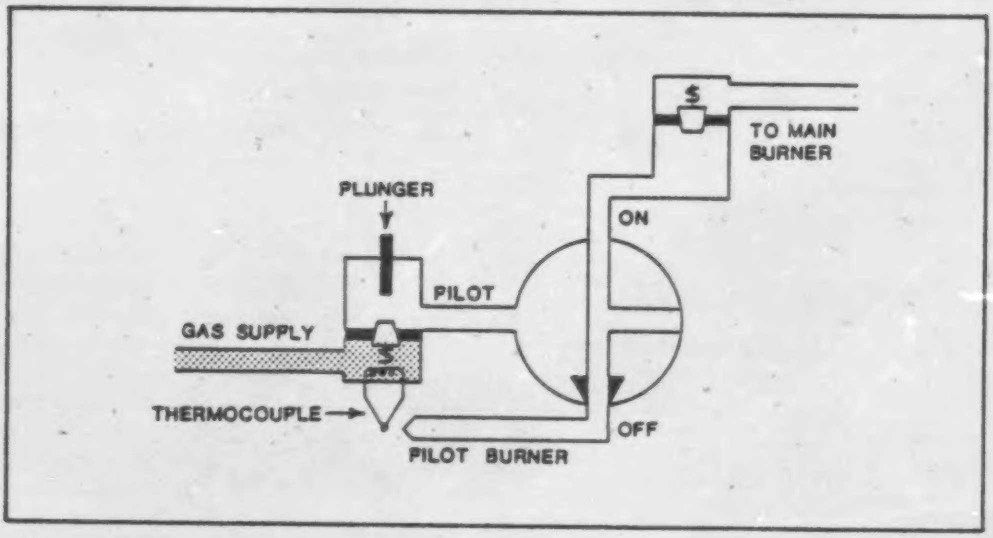

S
TO MAIN BURNER
PLUNGER
ON
PILOT
GAS SUPPLY
S
THERMOCOUPLE
OFF
PILOT BURNER

Figure 19. Schematic of Gas Valve in OFF Position.

Figure 20 shows the gas valve in the pilot position used for lighting the pilot flame. The control knob is first set to the pilot position. This allows no gas flow because there is no pilot flame, and the thermocouple-controlled valve remains closed. Pressing the light plunger opens this valve manually and allows the pilot flame to be lighted. The plunger must be held down for about 1 minute to allow the thermocouple to reach operating temperature. The pilot will then continue to burn when the plunger is released. Only the pilot burner is supplied with gas in the pilot position; no gas can reach the main burner.

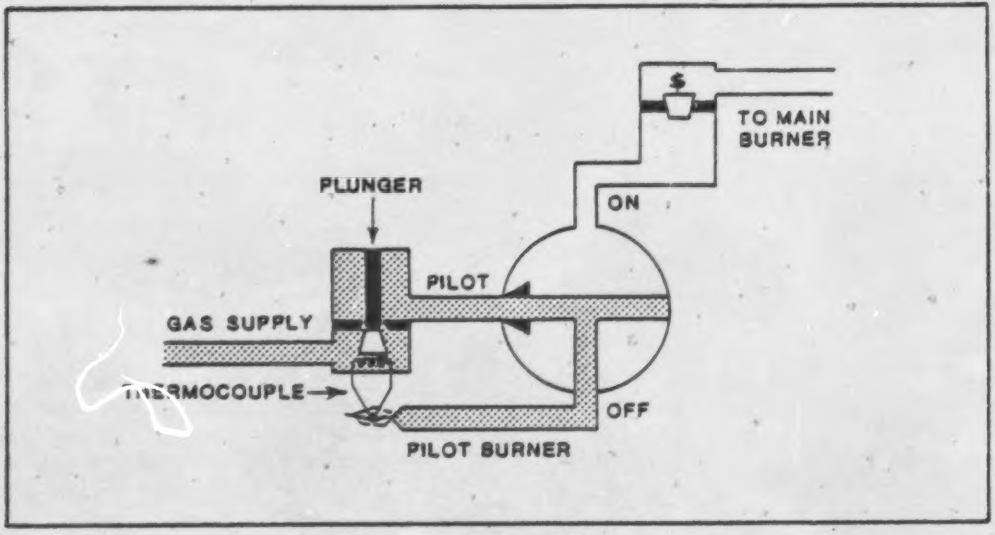


Figure 20. Gas Valve in Pilot Position.

Figure 21 shows the gas valve in the ON position before a call for heat. The pilot flame is burning, and gas is supplied to the main burner valve. This valve is controlled by an external thermostat and will open (Figure 22) when

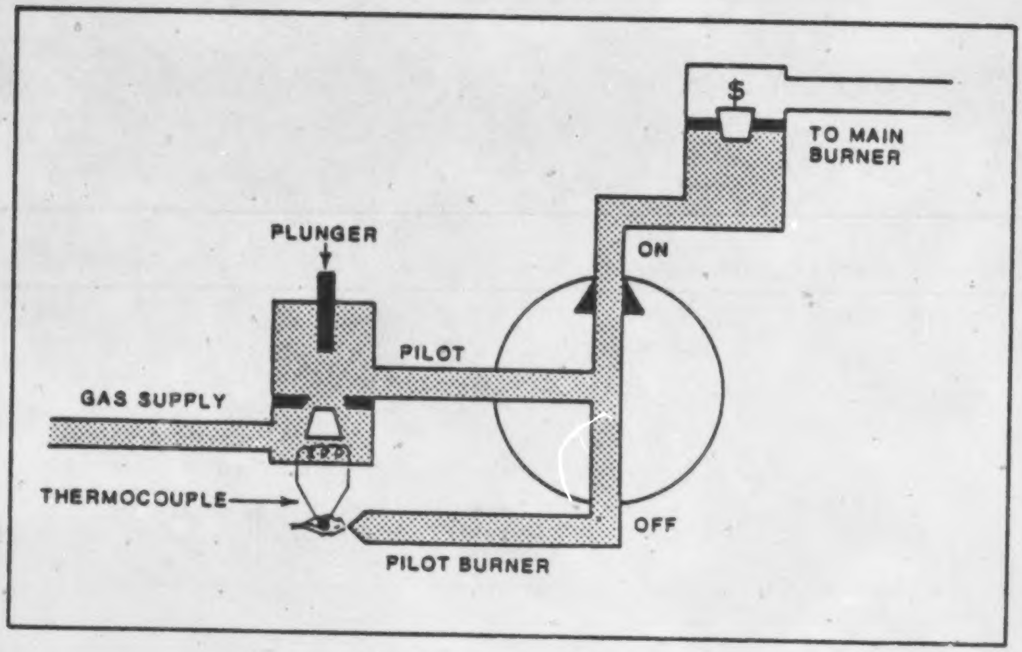

TO MAIN BURNER
PLUNGER
ON
PILOT
GAS SUPPLY
THERMOCOUPLE
OFF
PILOT BURNER

Figure 21. Gas Valve in ON Position Before a Call for Heat.

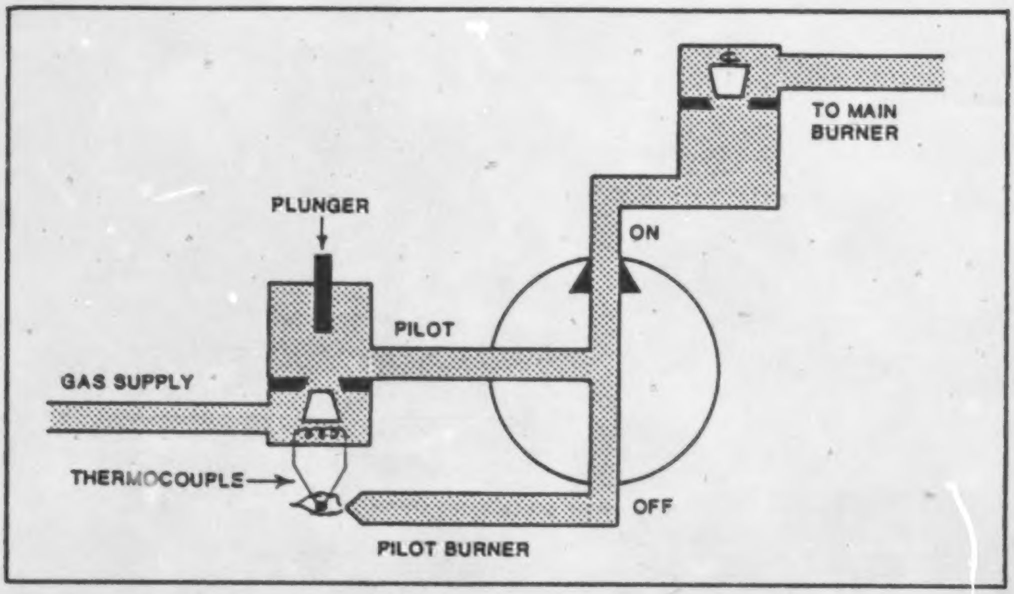

TO MAIN BURNER
PLUNGER
ON
PILOT
GAS SUPPLY
THERMOCOUPLE
OFF
PILOT BURNER

Figure 22. Gas Valve in ON Position After a Call for Heat.

there is a call for heat. Gas then flows to the main burner and is ignited by the pilot. If the pilot flame goes out at any time, the thermocouple-controlled valve closes. The operation of this valve may be checked by measuring the time required for the valve to close. The gas valve is first set to the pilot position. The pilot is lighted and is allowed to burn for a few minutes. Then the gas valve is turned OFF, and a timer is started. The closing of the thermocouple valve is indicated by a click. If this requires more than 2 1/2 minutes, the valve should be replaced.

The gas valve also includes a pressure regulator to control the gas manifold pressure. The manifold pressure is low (less than 1 psi) and is measured in inches water gauge (in w.g.). The correct manifold pressure for natural gas is 3 1/2 to 4 in w.g. For propane the correct pressure is 11 in w.g.

Figure 23 shows the measurement of manifold pressure with a water-filled U-tube manometer. The pressure is indicated by the difference in water levels in the two arms of the manometer. Most gas valves or manifolds have a port for such measurement. When the plug is replaced, it should be sealed with an approved pipe dope, as should all gas pipe connections.

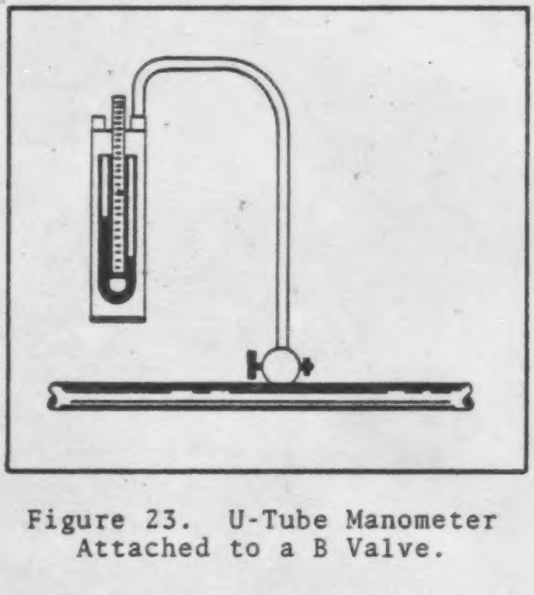


Figure 23. U-Tube Manometer Attached to a B Valve.

Figure 24 shows the complete burner assembly used with the heat exchanger in Figure 13. This system employs three main burners with crossover ignitors to light one burner from another.

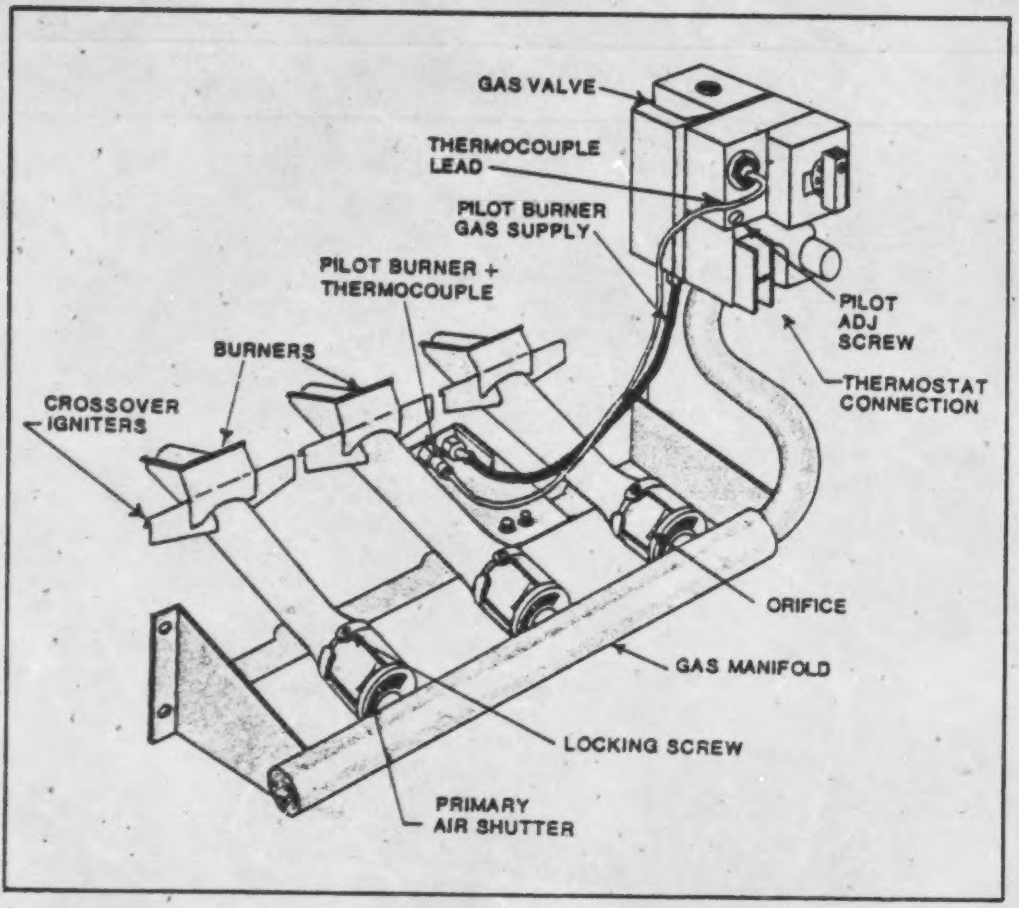

GAS VALVE
THERMOCOUPLE LEAD
PILOT BURNER GAS SUPPLY
PILOT BURNER + THERMOCOUPLE
BURNERS
CROSSOVER IGNITERS
PILOT ADJ SCREW
THERMOSTAT CONNECTION
ORIFICE
GAS MANIFOLD
LOCKING SCREW
PRIMARY AIR SHUTTER

Figure 24. Complete Burner Assembly.

Fan control in gas-fired furnaces is usually accomplished by thermal switches located on the heat exchanger.

FURNACE SELECTION

The type of furnace selected for a particular application depends upon the heating load and the cost and availability of fuels and electrical energy in the area.

In areas where the natural gas supply is abundant, natural gas is the most economical source of heat energy. Equipment cost, maintenance, and fuel costs are generally less than for oil-fired furnaces. Electric furnaces are less expensive and require even less maintenance, but electric heat is usually the most expensive in terms of energy costs.

Electric furnaces are popular in areas where the air conditioning load in summer far exceeds the heat load in winter. In such cases, the savings in the initial cost of the equipment and in not having to extend gas lines is sufficient to warrant paying a higher price for limited heating requirements. Electric furnaces are often incorporated as auxiliary heaters in heat pump systems.

Oil heating is used extensively in areas in the North and East where natural gas is unavailable and heating requirements make electric heating costs too high. Oil-fired furnaces are more expensive and require more maintenance than either electric or gas-fired furnaces, but they offer the advantage of a long-range fuel supply that is not dependent on a constant delivery system.

Oil-fired furnaces have a nasty habit of blowing up if not maintained properly.

EXERCISES

1. State the configuration of the warm air furnace most suited for the following applications and explain each choice briefly.
   a. House with attic space for air ducts and no basement.
   b. House with basement.
   c. House with no basement but ductwork in the floor.
   d. House with no basement but crawlspace under the floor.
2. Explain the controls necessary for the safe operation of an electric furnace.
3. Explain the flame detector systems of the following:
   a. An oil-fired furnace.
   b. A gas-fired furnace.

   Explain why the system used with each is unsuitable for the other.
4. Explain the ignition system of an oil burner.
5. Draw diagrams showing gas flow in the gas valve of a gas-fired furnace under the following conditions:
   a. Lighting pilot with plunger depressed.
   b. Gas valve "ON" but no heat requested.
   c. Gas valve "ON" and heat requested.
6. Explain how the following quantities are adjusted in a gas-fired furnace:
   a. Primary air supply.
   b. Gas manifold pressure.
   c. Pilot flame size.

LABORATORY MATERIALS

Gas-fired furnace.
Gas supply.
Thermostatic control for furnace.
Plastic spray bottle of salt solution.
Hand-held butane torch.
Screwdrivers and wrenches (as appropriate to furnace).
General controls adapter No. 103050G.
d.c. millivoltmeter.
Water-filled U-tube manometer with valve.
Watch with "second" indicator.
Thermometer 0-300°f.

LABORATORY PROCEDURES

1. Close gas supply valve at gas main and disconnect all electrical power to the furnace.
2. Remove furnace cover plates.
3. Draw in the Data Table a sketch of the major furnace components and their location in the cabinet. Include blower, burner, gas valve, heat exchanger, filter, flue, room air inlet and outlet.
4. Draw a diagram showing the shape of the heat exchanger.
5. Remove the main gas burners and draw a diagram showing their construction. Include the orifice and the primary air shutter.
6. Draw a diagram of the pilot burner and thermocouple rod.
7. Draw and label a diagram of the furnace gas valve, showing all controls.

8. Reassemble main burners. Install the thermocouple adapter and the manometer as indicated in the Subject Matter. Connect millivoltmeter to adapter.

9. Turn on the gas supply to the furnace and connect electrical power. BEWARE OF EXPOSED WIRES AND TERMINALS!

10. Light pilot, following instructions in the Subject Matter.

11. Record the thermocouple voltage in the Data Table.

12. Inspect the pilot flame. Turn OFF and clean the pilot burner if necessary. Adjust the pilot to the proper level, as indicated in the Subject Matter. Record the new thermocouple voltage.

13. Turn OFF the gas valve and measure the time for "dropout" of the thermocouple-controlled valve. Record this value (in seconds) and the thermocouple voltage in the Data Table.

14. Relight the pilot burner.

15. Set the gas valve to "ON" and set the thermostat for a heat demand. Observe the main burner as it lights.

16. Measure the gas manifold pressure with the manometer. Adjust the pressure to the proper range and record the pressure in the Data Table.

17. Set the primary air shutter to provide too little primary air (momentarily) and describe the results in the Data Table.

18. Set the primary air shutter to provide too much primary air and describe the results in the Data Table.

19. Set the primary air shutters for the correct amount of primary air and describe the result in the Data Table.

20. With the primary air supply properly adjusted and the main burners on, adjust the manifold pressure downward and observe the flame. Describe the results in the Data Table.

21. Adjust the manifold pressure to above the normal operating range and record the results.
22. Set the manifold pressure to the proper value. Turn OFF the furnace and remove the manometer and thermocouple adapter.
23. Return the furnace to operation. Spray salt solution into combustion chamber and check output air with butane torch. Record the results of the leak test in the Data Table.
24. Set the control thermostat to a level requesting no heat and allow the furnace to cool for a few minutes.
25. Turn the thermostat to request heat. Measure the time between main burner ignition and fan turn-ON and record in the Data Table.
26. Lower the thermostat to request no heat and measure and record the time between main burner turn-OFF and fan turn-OFF.
27. Turn the furance back ON and allow it to operate. Measure and record the temperature of the air entering the furnace, the air to the furnace output, and the exhaust gas.
28. Turn OFF the furnace and replace the cover plates.
29. Write a brief description of the condition of the furnace, the test that was made, and any corrections that were made. Word it as a service technician would report work to a customer.

DATA TABLE

SKETCHES OF FURNACE

Layout of furnace components:

Heat Exchanger:

Main Burner:

Pilot Burner:

Gas Valve:

Data Table. Continued.

Thermocouple voltage before adjustment: ______________
Thermocouple voltage after adjustment: ______________
Time for dropout: ____________
Thermocouple voltage at dropout: ______________
Manifold pressure: ______________
Flame with too little primary air:

Flame with too much primary air:

Flame with manifold pressure too low:

Flame with manifold pressure too high:

Results of heat exchanger leak test:

Time from main burner ignition to fan-ON: ______________
Time from main burner off to fan-OFF: ______________
Temperature of entering air: ______________
Temperature of heated air: ____________
Temperature of exhaust: ____________

Data Table. Continued.

DESCRIPTION OF SERVICE CALL AND EQUIPMENT CONDITION

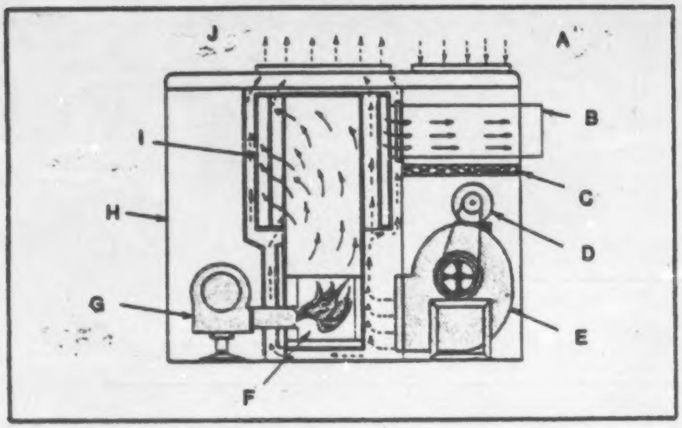
REFERENCES

Howell, Ronald H. and Sauer, Harry J., Jr. Environmental Control Principles. New York: The American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc., 1978.

Russell, Allen. Getting Started in Heating and Air Conditioning Service. Birmingham, MI: Business News Publishing Co., 1973.

TEST

1. A low-boy warm air furnace will probably be located
   a. in the equipment room of a house without a basement.
   b. in an attic.
   c. in a basement.
   d. in a mobile home.
2. A counter flow warm air furnace is usually used
   a. when ductwork is located in an attic.
   b. when ductwork is located under the floor of a house with a basement.
   c. when ductwork is located under the floor of a house without a basement.
   d. without ductwork.
3. Advantages of electric furnaces include
   a. small size.
   b. simplicity and safety of control.
   c. no need for ductwork.
   d. All of the above are true statements.
   e. Only a and b are true statements.
4. Thermally actuated switches are used
   a. to turn the fan ON and OFF in gas-fired furnaces.
   b. as over-temperature shutoff devices in electric furnaces.
   c. to turn on the oil burner in oil-fired furnaces.
   d. All of the above are true statements.
   e. Only a and b are true statements.
5. Identify the following components of an oil-fired furnace by placing the proper letter from the diagram in each space.



_____ Oil burner.
_____ Supply air duct.
_____ Flue outlet.
_____ Combustion chamber.
_____ Heat exchanger.

6. Which of the following is true of both gas-fired and oil-fired furnaces?
   a. The combustion chamber is lined with a refractory material.
   b. Combustion air is supplied by a blower.
   c. Eighty percent of the heat energy is transferred to the room air.
   d. The presence of the flame is detected by a thermocouple.
   e. Both b and c.

7. Secondary combustion air is supplied to a gas burner
   a. by a blower.
   b. by room air entering the combustion chamber.
   c. by air drawn into the burner throat by the gas stream.
   d. None of the above are true statements.

8. Which of the following statements is not true of an oil burner?
   a. All combustion air is provided by a blower.
   b. Deflector vanes on the air tube cause the fuel-air mixture to swirl for better combustion.
   c. The ignition system consists of a transformer and electrodes.
   d. The flame detector is a photocell that produces a voltage when visible light strikes it.
   e. All of the above are true statements.

9. If the primary air adjustment of a gas burner is opened too far
   a. the flame will be yellow and may smoke.
   b. the pilot flame may be blown out when the furnace turns OFF.
   c. the pilot may be blown out when the furnace turns ON.
   d. the flame may hiss or "roar."
   e. Both b and d are true statements.
   f. Both c and d are true statements.

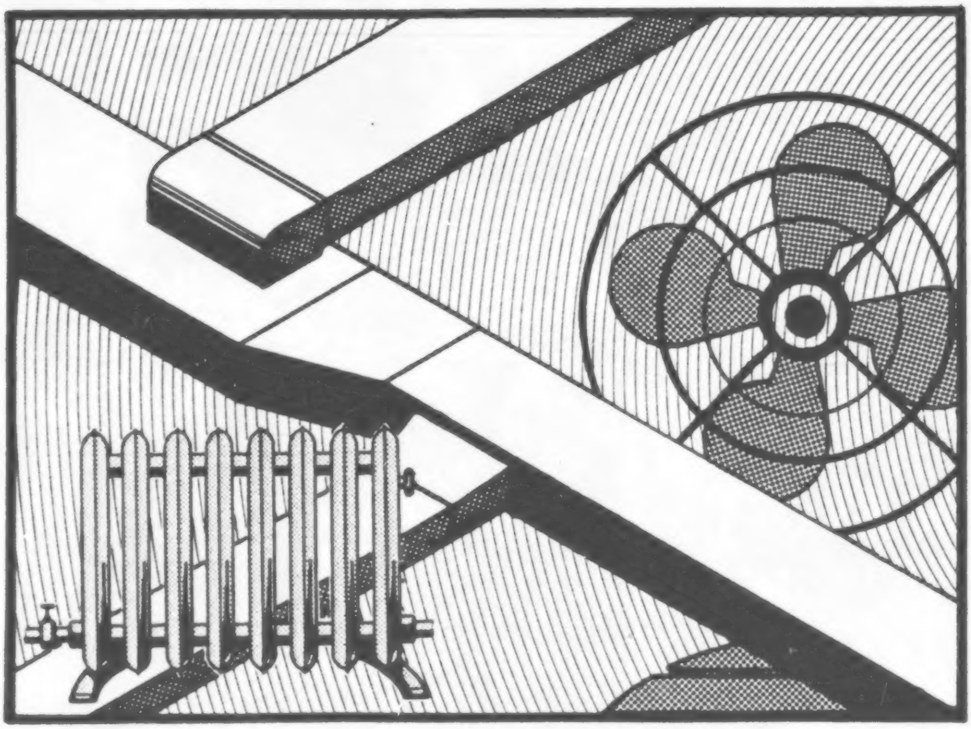
10. If the pilot flame of a gas-fired furnace goes out, the thermocouple voltage drops, and
   a. a valve turns OFF the main burner fuel supply.
   b. a valve turns OFF the pilot burner fuel supply.
   c. a switch turns OFF the blower electrical supply.
   d. Both a and b are true statements.
   e. All of the above are true statements.

ecut

ENERGY TECHNOLOGY

CONSERVATION AND USE

HEATING, VENTILATING, AND AIR CONDITIONING



MODULE HC - 05

BOILERS FOR HEATING APPLICATIONS

CORD CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

INTRODUCTION

Most large heating systems and many small ones employ steam or hot water as a heat transfer medium. This water is heated and, in most cases, vaporized in a gas or oil-fired boiler. The three basic boiler designs are the fire-tube boiler, the water-tube boiler, and the cast iron boiler. The most common boiler for heating application is a fire-tube boiler called the "Scotch marine boiler."

This module discusses the characteristics and applications of the three boiler types and the construction details of the Scotch marine boiler. Oil and gas burners, flame safeguard systems, fuel delivery systems, and boiler control are also described. The laboratory exercise consists of a field trip on which students will observe and describe an industrial boiler.

PREREQUISITES

The student should have completed Module HC-04, "Residential Heating Equipment."

OBJECTIVES

Upon completion of this module, the student should be able to:

1. List and describe the three basic types of boilers. State the steam pressure ranges and common applications of each type.
2. Draw and label a diagram of a 3-pass Scotch marine boiler. Identify the following parts:

   a. Combustion tube.
   b. Flue tubes.
   c. Rear header.
   d. Front header.
   e. Smoke box.

3. Explain the difference in wet-back and dry-back boilers and state two reasons for the greater popularity of the dry-back boiler.
4. Explain the purpose and operation of a blow-down tank.
5. Describe briefly the operation of the following burners and state the fuels (oil type) burned by each oil burner.
   a. Mechanical atomizing oil burner.
   b. Air or steam atomizing oil burner.
   c. Horizontal rotary oil burner.
   d. Gas ring burner.
6. Given a diagram of a gas train, identify it as UL, FM, or FIA approved. State the nine common elements contained in each of these gas trains.
7. Describe the operation of the following flame safeguard systems:
   a. Infrared detection.
   b. Ultraviolet detection.
   c. Flame rectification.
8. Describe the control sequence in the turn ON and turn OFF processes of a gas-fired boiler with low fire starting and flame rectification.
9. List and explain the four systems of firing rate control.
10. Visit an industrial boiler installation on a field trip. Observe and record information on the boiler and draw diagrams of the system.

SUBJECT MATTER

BOILER TYPES

Three basic boiler types in common use are the fire-tube boiler, the water-tube boiler, and the cast iron boiler. The characteristics and applications of each type are presented below.

FIRE-TUBE BOILER

In a fire-tube boiler the hot flue gas passes through flue tubes that are submerged in the water within the boiler pressure vessels. Figure 1 shows a horizontal return tube boiler. This type of fire-tube boiler was a popular industrial boiler in the past, and many remain in service. HRT boilers have efficiencies as high as 70% and have been used for pressures up to 250 pounds. These boilers are no longer being built because of (1) the high construction cost of the firebox and support structure and (2) their relatively low efficiency compared to other boiler designs. The Scotch marine boiler (discussed in detail later in this module) is an improved fire-tube boiler design derived from the HRT boiler.

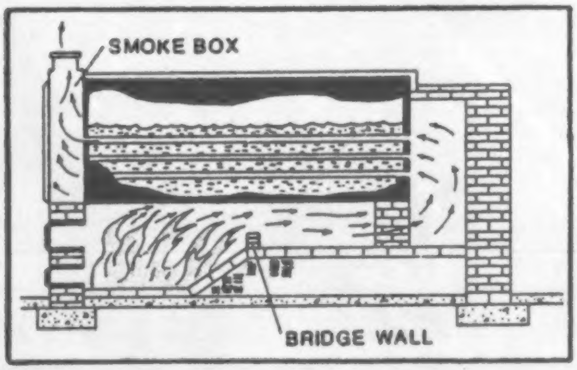
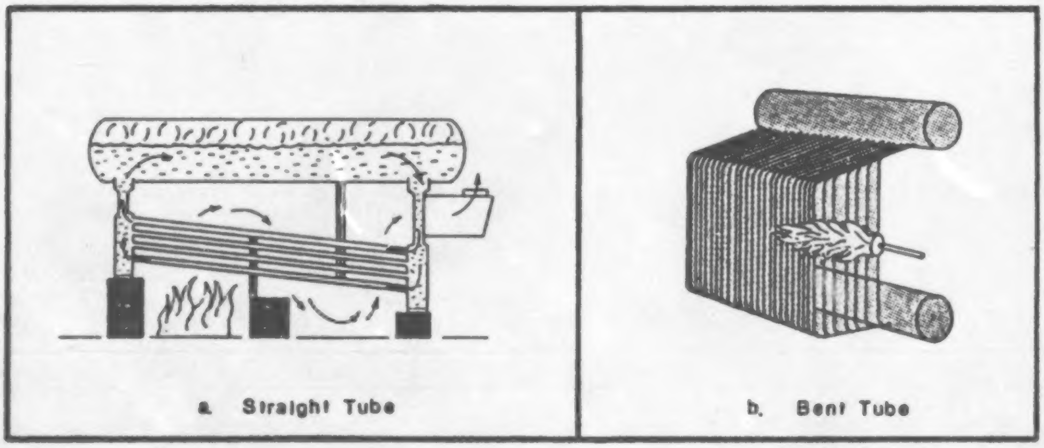


Figure 1. Horizontal Return Tube Boiler (HRT).

WATER-TUBE BOILERS

In a water-tube boiler the hot flue gas passes around pipes filled with water and steam. The boiler consists of drums for the storage of water and steam and pipes for heat transfer. Water-tube boilers are usually used for high steam pressure (about 150 psi) but are sometimes found in low pressure heating service.

Figure 2 shows the two basic categories of water-tube boilers. Straight-tube boilers (Figure 2a) are an old design. Although some are still in service, most modern water-tube boilers are of the bent-tube design (Figure 2b). These boilers are used whenever high capacity of high pressure steam is required. Boilers delivering 1,000,000 pounds of steam per hour at 5000 psi are not uncommon in large power plants. Bent-tube boilers operating at efficiencies of 78–80% produce most of the electrical energy in the United States.


a. Straight Tube

b. Bent Tube

Figure 2. Water-Tube Boilers.

Since water-tube boilers are not extensively employed in heating service, they will not be examined in detail in this module. The burner types, fuel systems, and control systems for Scotch marine boilers (discussed later in this module) also apply to water-tube boilers.

CAST IRON BOILERS

Cast iron boilers (Figure 3) are used primarily for low pressure (5 to 15 psi) heating service. They consist of cast iron segments that may be stacked together to form a boiler of the desired dimensions. The primary advantage of cast iron boilers is that they can be erected in relatively small spaces and in existing structures where water-tube or fire-tube boilers cannot be moved into place.

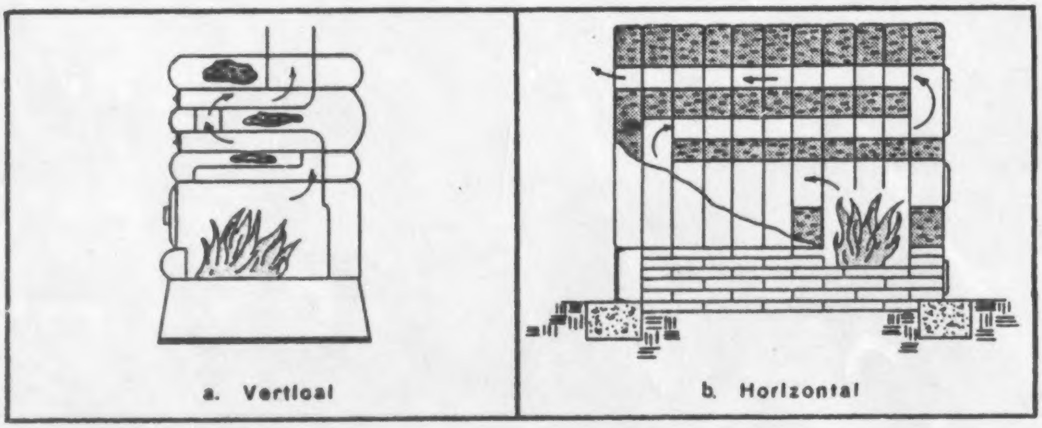


Figure 3. Cast Iron Boilers.

The vertical design (Figure 3a) requires little floor space and is often found in small commercial buildings and light industrial plants. The horizontal design (Figure 3b) is a larger boiler and is common in central heating plants of older buildings. Few cast iron boilers are installed today because of the high cost of labor involved in erecting them.

Small cast iron boilers are fired by oil or gas burners similar to those used in residential heating equipment (see Module HC-04, "Residential Heating Equipment"). Figure 4 is a diagram of a small gas-fired cast iron boiler that uses natural convection draft and a continuous gas pilot.

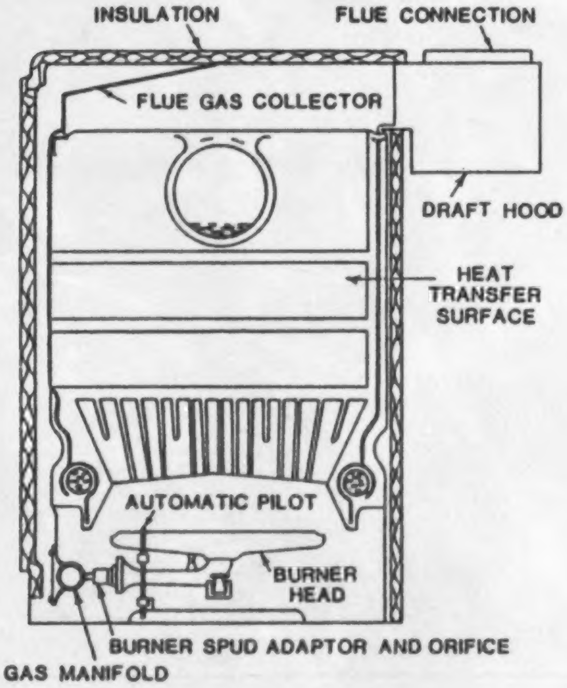

INSULATION
FLUE CONNECTION
FLUE GAS COLLECTOR
DRAFT HOOD
HEAT TRANSFER SURFACE
AUTOMATIC PILOT
BURNER HEAD
BURNER SPUD ADAPTOR AND ORIFICE
GAS MANIFOLD

Figure 4. Small Gas-Fired Cast Iron Boiler.

Larger cast iron boilers use forced draft and burners similar to those described later for Scotch marine boilers. The same fuel delivery and control systems are also used.

SCOTCH MARINE BOILER

As the name implies, this boiler, shown in Figure 5, was developed in Scotland for shipboard application. It is not a separate boiler type. Rather, it is a fire-tube boiler designed to replace the HRT boiler.

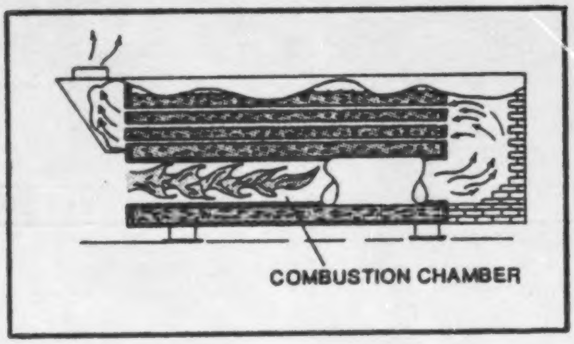
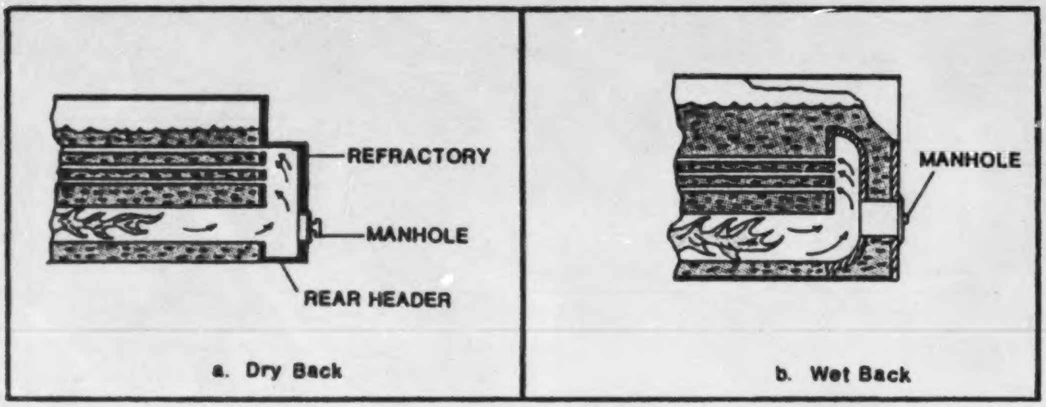


Figure 5. Scotch Marine Boiler.

The combustion chamber of the Scotch marine boiler is a tube surrounded by the water in the pressure vessel. This design affords maximum heat transfer and eliminates the need for a refractory lining in the combustion chamber. Additional energy transfer occurs as the combustion gas passes through the flue tubes.

The Scotch marine boiler is produced with two basic designs of rear header. This is the area where the flue gas changes direction, and it is subject to damage unless protected from the heat of the gas. The rear header of the dry-back boiler (Figure 6a) is a box lined with a refractory material. The wet-back boiler (Figure 6b) uses a water filled header that is an integral part of the pressure vessel.

The wet-back boiler has the advantage of containing no refractory material in the rear header, but it has the disadvantages of greater difficulty of construction and limited access to the flue tubes. These tubes must be cleaned and inspected periodically. Thus, the dry-back boiler is more popular even though the refractory material in its header must be replaced after a few years of operation.



a. Dry Back

b. Wet Back

Figure 6. Rear Header Design for Scotch Marine Boilers.

The Scotch marine boiler is the most popular type for operating pressures up to 150 psi. It has a standard operating efficiency of 80% and accounts for 65% of the commercial and industrial boiler market. Scotch marine boilers are available as packaged units to develop steam pressure in the ranges of 0 to 15 psi, 15 to 150 psi, and 150 to 250 psi, with capacities from 500 to 25,800 pounds of steam per hour.

The remainder of this module describes the features of the packaged Scotch marine boiler.

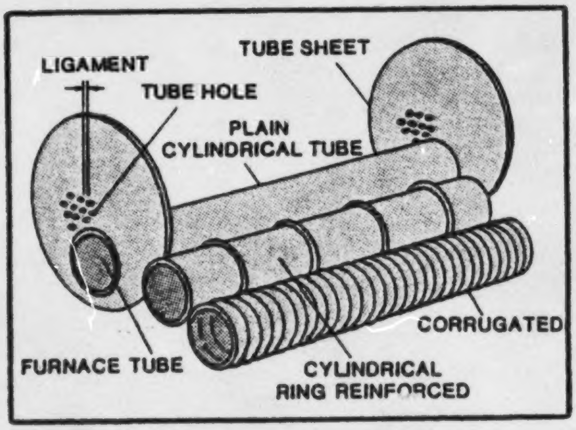
SCOTCH MARINE BOILER CONSTRUCTION

PRESSURE VESSEL

The ends of the boiler pressure vessel are called "tube sheets" (Figure 7). They contain holes for the furnace tube and flue tubes. The ligament, which is the spacing between the flue tubes, is typically about three-fourths of an inch.

Low pressure boilers use the plain cylindrical type of furnace tubes. Higher pressure boilers may use a ring reinforced cylinder or a corrugated cylinder. The latter is seldom used because of combustion problems due to eddy currents caused by the corrugations.

Figure 7. Tube Sheets and Furnace Tubes.


LIGAMENT
TUBE SHEET
TUBE HOLE
PLAIN CYLINDRICAL TUBE
CORRUGATED
FURNACE TUBE
CYLINDRICAL RING REINFORCED

The furnace tube and tube sheets are welded together, Then the boiler shell (Figure 8) is completed. The flue tubes are added and sealed into place. Three methods can be used to seal the tubes, as shown in Figure 9. In low pressure boilers the ends of the tubes are flared to form a seal and reduce resistance to gas flow. In higher pressure boilers the tube ends can be beaded for extra strength. The end of the tubes in the rear header are often welded in place in high pressure boilers.

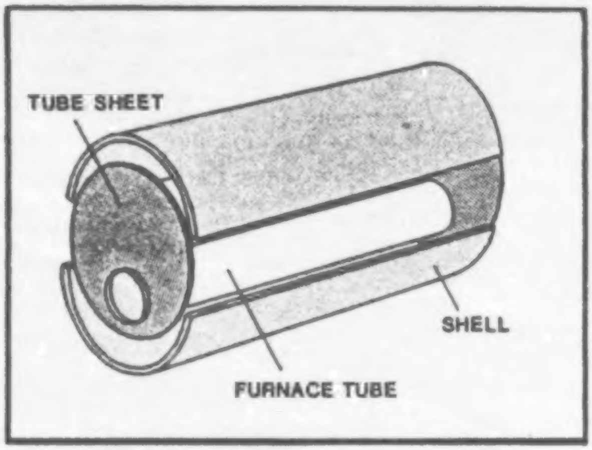


Figure 8. Boiler Shell.

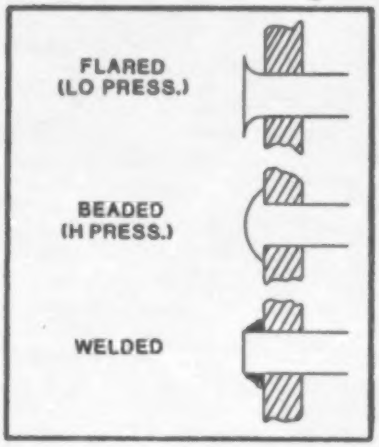
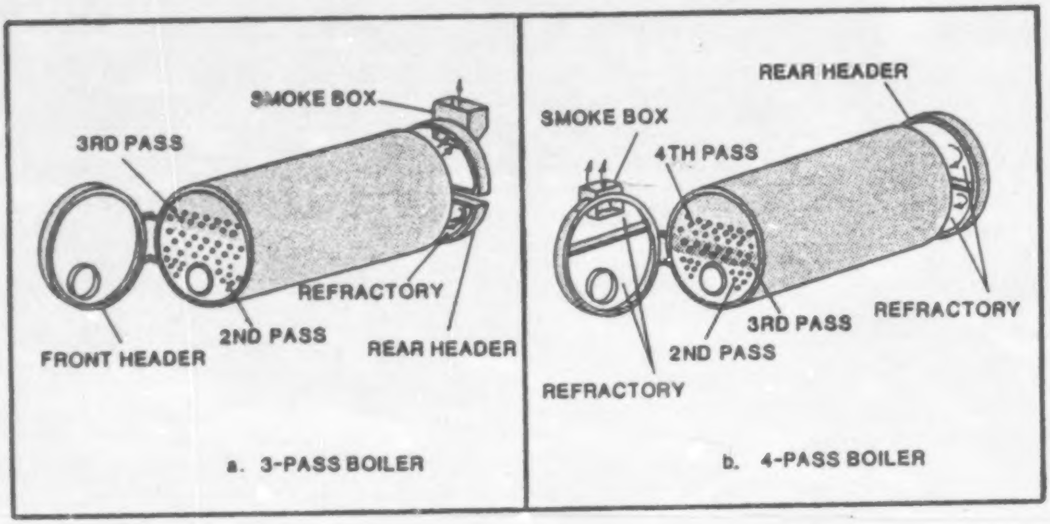


Figure 9. Sealing Flue Tubes.

HEADERS AND SMOKE BOXES

Headers are plenum boxes that receive the flue gases, reverse their direction, and direct them into the next boiler pass. The smoke box is the output part for the flue gases. Boilers are available with 2, 3, or 4 passes. The boiler in Figure 5 is a 2-pass boiler. Figure 10a shows a 3-pass boiler, and Figure 10b shows a 4-pass boiler. The front and rear header designs and smoke box location are also shown in Figure 10.

The number of boiler passes does not dictate boiler efficiency. Two-pass boilers have the same efficiency as 4-pass boilers. The number of passes does increase the resistance to flue gas flow and provides higher combustion chamber pressure in forced draft systems.


SMOKE BOX
3RD PASS
REFRACTORY
2ND PASS
FRONT HEADER
REAR HEADER
REAR HEADER
SMOKE BOX
4TH PASS
3RD PASS
REFRACTORY
2ND PASS
REFRACTORY

a. 3-PASS BOILER

b. 4-PASS BOILER

Figure 10. Addition of Headers and Smoke Boxes.

INSULATION AND JACKETING

The boiler vessel is covered with two or three inches of insulation to reduce heat loss. This is covered with an outer jacket, or lagging, to prevent damage. The boiler is then fitted with legs or skids to support it on its foundation.

WATER CONTROLS

Figure 11 shows the condensate tank, feedwater pump, and water level controls of a typical boiler. The water level controller turns on the feedwater pump and opens the

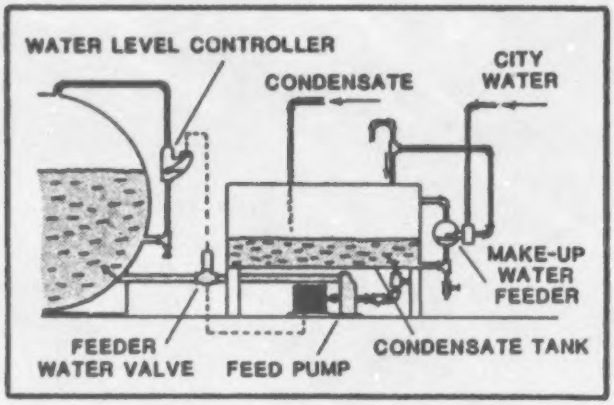

WATER LEVEL CONTROLLER
CONDENSATE
CITY WATER
MAKE-UP WATER FEEDER
FEEDER WATER VALVE
FEED PUMP
CONDENSATE TANK

Figure 11. Feed Pump and Condensate Tank.

feedwater valve when the boiler water level drops. If the level drops too far, this controller turns off the burner and sounds an alarm. The condensate tank receives condensed water from the heating system. A makeup water feeder adds city water to compensate for any losses.

Sedimentation of scale and suspended material (Figure 12) occurs in all boilers and must be removed periodically by manually opening the blow-down valve connected to the lowest point of the boiler. This pipe leads to the blow-down tank shown in Figure 13. This tank allows steam to vent through a steam pipe to the outside air and channels the hot water into the sewer.

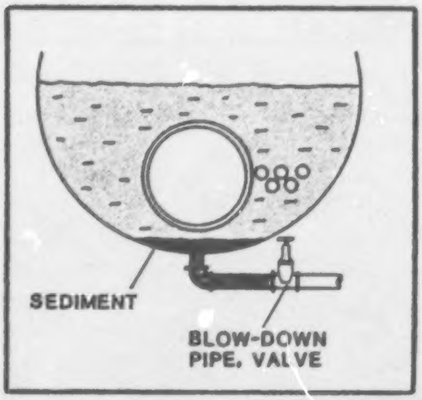

SEDIMENT
BLOW-DOWN PIPE, VALVE

Figure 12. Sediment in Boiler.

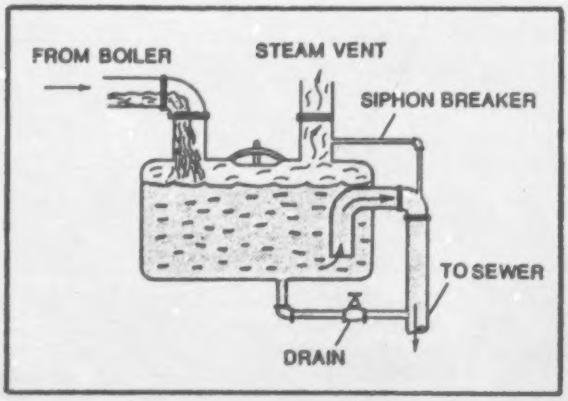

FROM BOILER
STEAM VENT
SIPHON BREAKER
TO SEWER
DRAIN

Figure 13. Blow-Down Tank.

COMBUSTION CONTROL

The burner and combustion controls are installed and the completed packaged boiler is ready for shipment. A variety of burners and control systems are commonly used with Scotch marine boilers. The same systems are also used on water-tube boilers and on larger cast iron boilers. The remainder of this module discusses the burners and controls in current service.

BURNERS

Boilers used for heating and most industrial applications are fired with natural gas or fuel oil. In either case the fuel must be mixed with the proper amount of air and burned completely.

COMBUSTION AIR

Air flow through a boiler can be accomplished by three mechanisms.

Natural Draft

Small cast iron boilers (Figure 4) have no mechanical blowers. The hot exhaust gas rises through the heat exchangers and flue, drawing room air into the combustion chamber. The major disadvantages of natural draft are low air flow rates and poor control.

Induced Draft

Air flow can be increased in some boilers by placing a blower in the exhaust system. The induction fan creates a lower pressure inside the combustion chamber and draws, or "induces," room air into the combustion chamber. The major disadvantage of induced draft is damage to the fan by hot flue gases.

Forced Draft

Most modern boilers use a forced draft system that incorporates an air blower into the burner assembly (Figure 14). The fan delivers the proper amount of combustion air, usually 30% more than the amount required for total combustion of the fuel. This assures complete burning and results in better heat transfer in the flue tubes. The blower also pressurizes the combustion chamber and forces flue gas through the tubes.

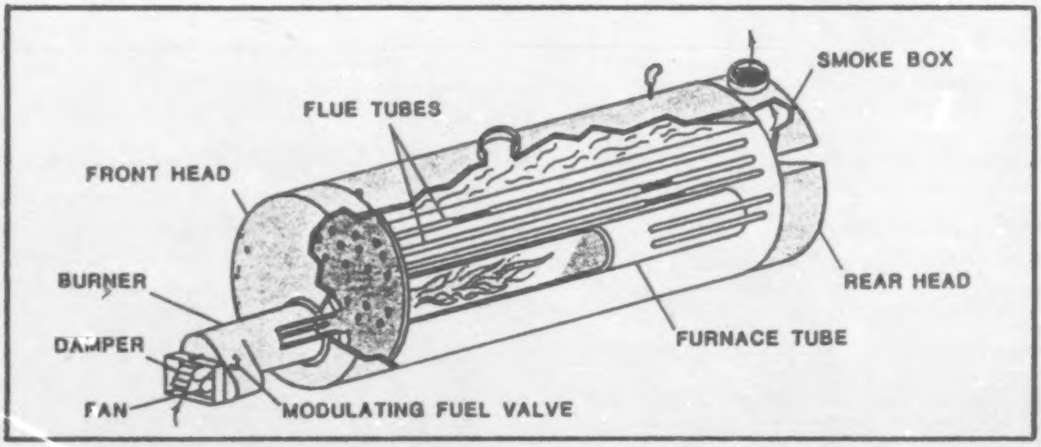

SMOKE BOX
FLUE TUBES
FRONT HEAD
BURNER
REAR HEAD
FURNACE TUBE
DAMPER
FAN
MODULATING FUEL VALVE

Figure 14. Typical Boiler (3-Pass, Forced Draft).

MECHANICAL ATOMIZING OIL BURNER

The nozzle tip of the mechanical atomizing oil burner (Figure 15) contains slots that cause the escaping oil to rotate and spray outward in a cone. Combustion air enters through a set of vanes that cause the air to spin, or "turbulate," for complete mixing with the oil spray. This is the same type of burner used in residential oil-fired furnaces. It is used primarily with lighter weight fuel oils.

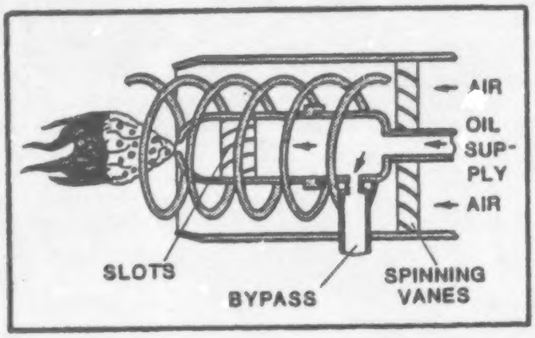
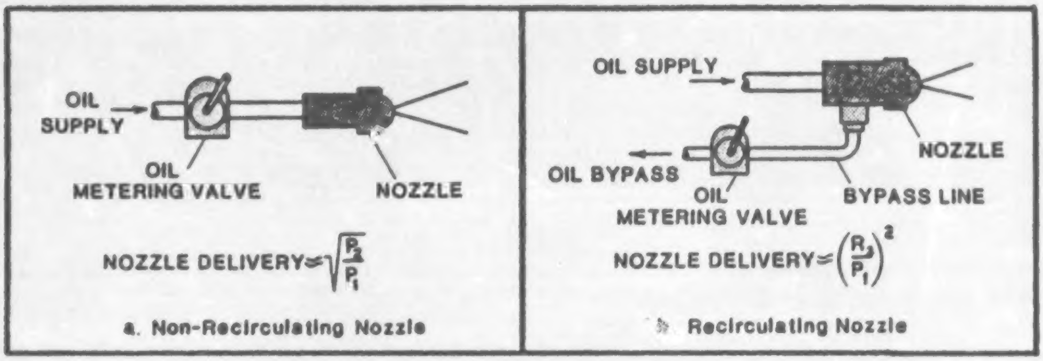


Figure 15. Mechanical Atomizing Oil Burner.

Two basic nozzle types can be used in mechanical atomizing oil burners. The non-recirculating nozzle (Figure 16a) consists of an oil metering valve in series with a spray nozzle. The fuel delivery rate of this nozzle depends upon the square root of the pressure at the spray nozzle. To reduce the fuel flow rate to one-half its maximum value the pressure must be reduced to one-fourth maximum. This pressure reduction would result in poor atomization of the oil. Thus, non-recirculating nozzles provide only limited control of combustion rate.

In the recirculating nozzle (Figure 16b) oil circulates past the spray nozzle through a metering valve. In this design the fuel delivery rate is proportional to the square of the pressure. Reducing oil flow to one-half can be accomplished by reducing pressure to three-fourths. This superior control makes the recirculating nozzle the most popular.


OIL SUPPLY
OIL METERING VALVE
NOZZLE
NOZZLE DELIVERY$\approx\sqrt{\frac{P_2}{P_1}}$
OIL SUPPLY
NOZZLE
OIL BYPASS
OIL METERING VALVE
BYPASS LINE
NOZZLE DELIVERY$\approx\left(\frac{P_2}{P_1}\right)^2$

a. Non-Recirculating Nozzle

b. Recirculating Nozzle

Figure 16. Nozzles Used in Mechanical Atomizing Oil Burners.

AIR OR STEAM ATOMIZING OIL BURNERS

In air or steam atomizing oil burners (Figure 17) the oil sprays through ports on the edge of a disk. A high velocity stream of air or steam atomizes the oil spray. Secondary combustion air enters around the burner nozzle. Air atomizing burners typically operate with an input air pressure of 10 to 20 psi. Steam atomizing burners require about 2% of the boiler steam output for their operation. Steam atomizing burners also require an auxiliary source of steam or compressed air during startup.

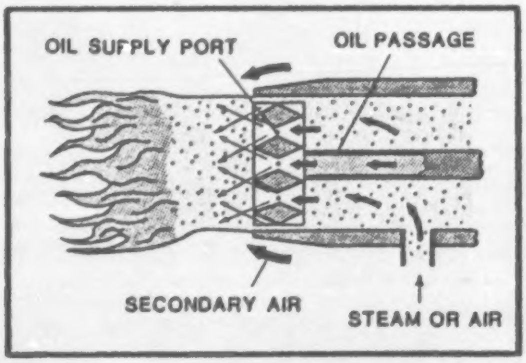

OIL SUPPLY PORT
OIL PASSAGE
SECONDARY AIR
STEAM OR AIR

Figure 17. Air or Steam Atomizing Oil Burner.

These are the most popular burners for large commercial boilers because they can efficiently burn any grade of fuel oil.

HORIZONTAL ROTARY OIL BURNER

The horizontal rotary oil burner (Figure 18) consists of a cup rotating at 3500 rpm in a fast moving air stream. Oil enters the center of the cup and is slung from its edge into the air stream. Air turbulence introduced by the shaper vanes aids in atomizing the oil. The advantages of this burner are its ability (1) to burn any oil and (2) to operate at low oil pressures. Its major disadvantage is high maintenance for repair of moving parts and cleaning.

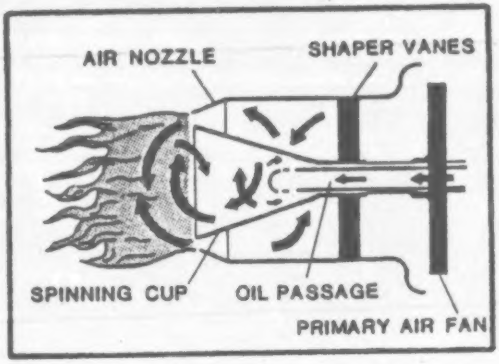


Figure 18. Horizontal Rotary Oil Burner.

GAS BURNER

Most forced draft boilers using gaseous fuels use the ring burner shown in Figure 19. The gas sprays from orifices around a ring manifold into an air stream that is turbulated by vanes on the manifold. In some boilers a gas burner is located around an oil burner so either fuel may be used.

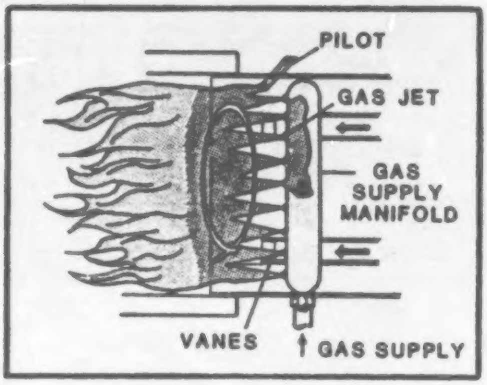


Figure 19. Gas Ring Burner.

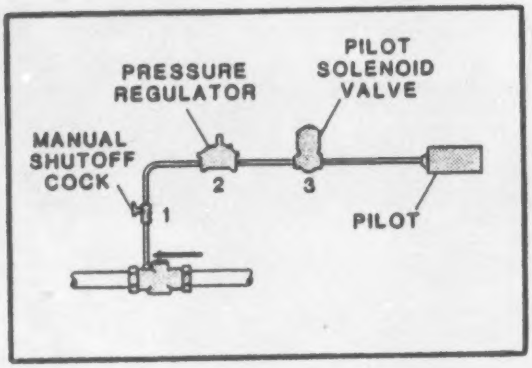
FUEL TRAIN CONTROLS

Three approval bodies govern the application of control equipment and sequence of control used to handle boiler fuels. These are Underwriters Laboratory (UL), Associated Factory Mutual (FM), and Factory Insurance Association (FIA). Virtually all boilers will employ one of these approved control systems.

PILOT GAS CONTROL

Figure 20 shows the gas train approved by UL, FM, and FIA for pilot gas control. An electrical signal from the control circuit opens the pilot solenoid valve, allowing gas to flow to the pilot burner. This gas is ignited with a spark ignitor. The gas supply to the main burner is turned ON only after the flame detector system verifies the pilot flame.

Figure 20. Gas Train for Pilot Gas Control.


PRESSURE REGULATOR
PILOT SOLENOID VALVE
MANUAL SHUTOFF COCK
2
3
1
PILOT

UL GAS CONTROL

Figure 21 shows the components of the UL approved gas train. Valves 7 and 8 are operated together, and both serve the same function – to shut off fuel to the main burner. If one of these valves should fail, the other will continue to interrupt gas flow. Valve 9 controls the fuel flow rate to the burner.

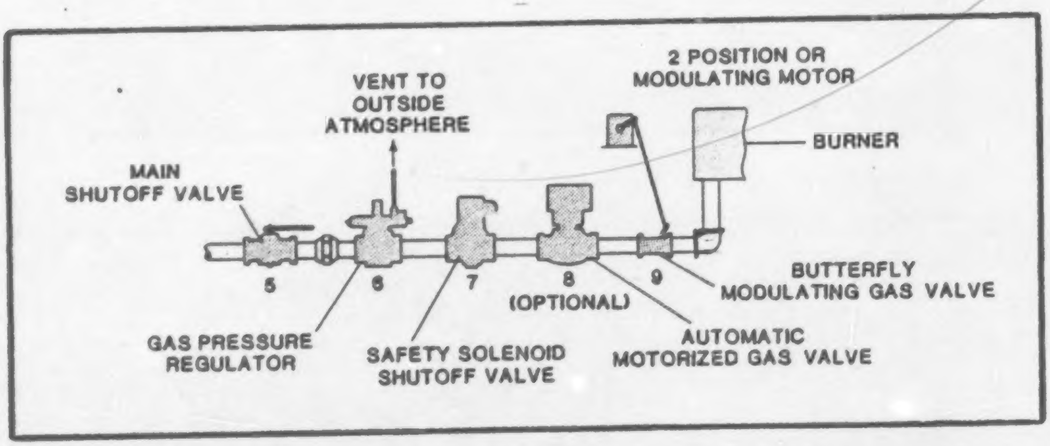

2 POSITION OR MODULATING MOTOR
VENT TO OUTSIDE ATMOSPHERE
BURNER
MAIN SHUTOFF VALVE
5
6
7
8 (OPTIONAL)
9
BUTTERFLY MODULATING GAS VALVE
GAS PRESSURE REGULATOR
SAFETY SOLENOID SHUTOFF VALVE
AUTOMATIC MOTORIZED GAS VALVE

Figure 21. UL Approved Gas Train.

FM GAS CONTROL

The FM approved gas train (Figure 22) incorporates the same valve arrangement as the UL system, with four additions. The low (10) and high (12) gas pressure switches prevent the opening of valves 7 and 8 if the proper gas pressure is not present. The main test fire valve (11) is used to test gas leakage through valves 7 and 8 in the closed position. A gas leak is indicated by bubbles in the water container when valve 11 is closed. Valve 8 has the additional feature of providing an electrical signal to indicate when the valve is closed. The ignition sequence cannot be initiated unless this valve is closed.

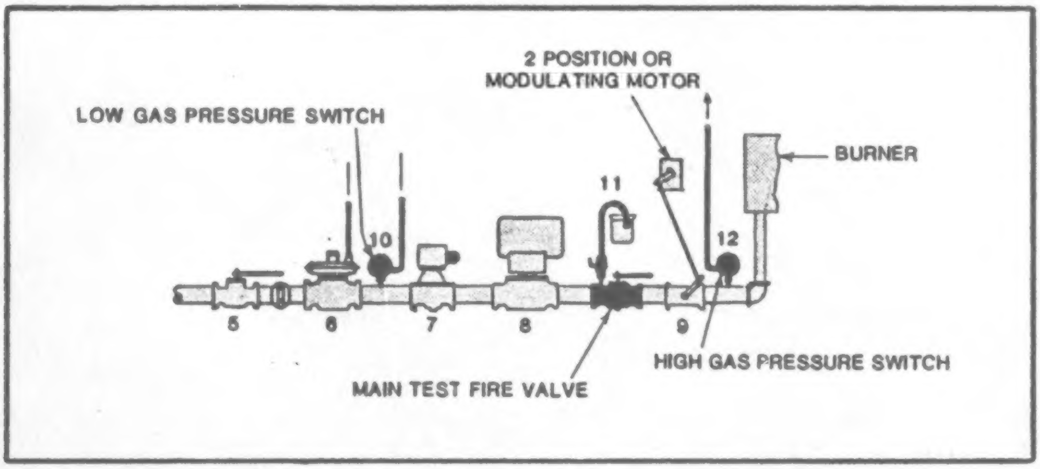

2 POSITION OR
MODULATING MOTOR
LOW GAS PRESSURE SWITCH
BURNER
11
10
12
5
6
7
8
9
HIGH GAS PRESSURE SWITCH
MAIN TEST FIRE VALVE

Figure 22. FM Approved Gas Train.

FIA GAS CONTROL

Figure 23 shows the FIA approved gas train. The solenoid valve (7) of the UL and FM trains is replaced with a motorized gas valve. A vent line is provided to vent any gas trapped between valves 7 and 8 to the atmosphere. The vent valve momentarily opens after the main burner is turned OFF.

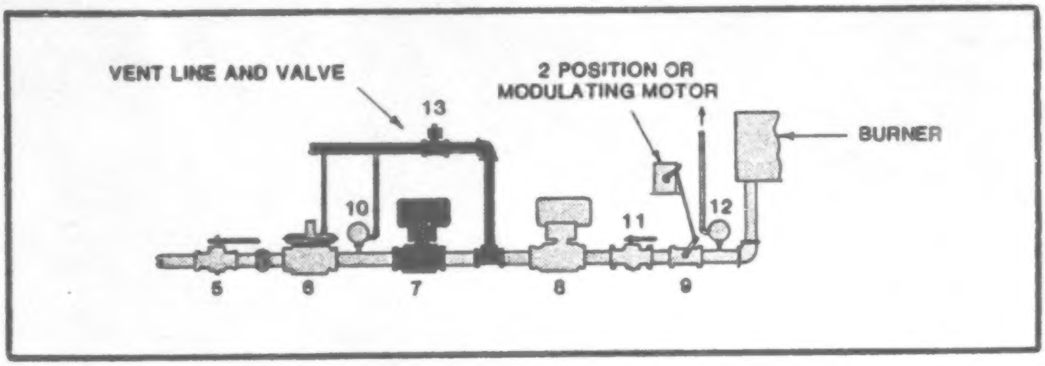


Figure 23. FIA Approved Gas Train.

OIL CONTROL

Figure 24 is a diagram of a typical oil control system. All three approval organizations require a spring-loaded solenoid oil valve between the pump and the burner. FM and FIA also require an oil pressure switch that allows the oil valve to open after the pump has reached operating pressure. The fuel flow rate of oil burners is controlled by valves located in the nozzles (Figure 16).

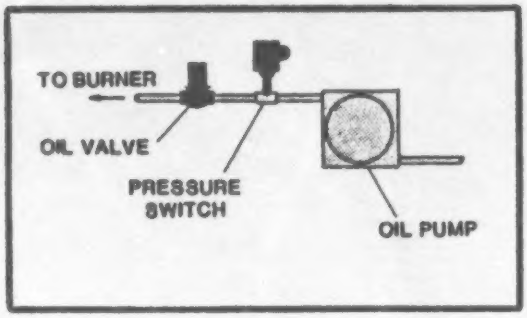


Figure 24. Oil Control System.

FLAME SAFEGUARD SYSTEMS

All boiler control systems incorporate a flame safeguard system that interrupts the fuel supply should the boiler flame go out. In gas-fired boilers the flame detector must confirm pilot burner operation before the main burner is turned ON.

The thermocouple flame detector system used in residential gas furnaces is also used with natural draft, gas-fired cast iron boilers (Figure 4), but the response time is too slow for larger gas burners. Visible light (cadmium sulfide) cells cannot be used with gas flames because good gas flames produce little visible light. Their use is confined almost entirely to residential oil burners.

INFRARED FLAME DETECTION

An infrared flame detector (Figure 25) consists of a lead sulfide cell in which electrical resistance decreases in the presence of infrared (heat) radiation from the oil or gas flame. Hot refractory also produces an infrared signal that might fool such a flame detector. To prevent this, the amplifier in the control circuit is designed to amplify the flickering "flame signal" at a frequency of 10 cycles per second and to ignore the constant refractory signal.

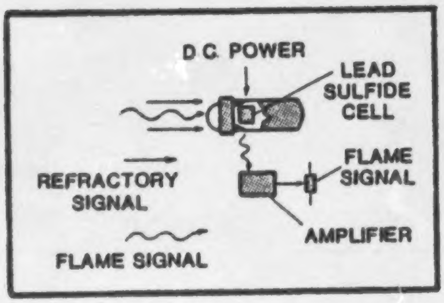

D.C. POWER
LEAD SULFIDE CELL
FLAME SIGNAL
REFRACTORY SIGNAL
AMPLIFIER
FLAME SIGNAL

Figure 25.
Infrared Detector.

ULTRAVIOLET FLAME DETECTION

The ultraviolet flame detector (Figure 26) consists of a glass tube containing two electrodes and a low-pressure gas. An a.c. signal is applied to the electrodes. In darkness, no current is conducted through the tube. In the presence of ultraviolet light from the oil or gas flame, the gas in the tube becomes conductive in one direction only. (Electrons move from the large electrode to the smaller one.) This rectifies the applied a.c. signal to produce a d.c. signal that confirms the presence of a flame. Ultraviolet detectors cannot be fooled by hot refractories; but they can be fooled by electric ignitor sparks and should be located where they are shielded from the ignitor.

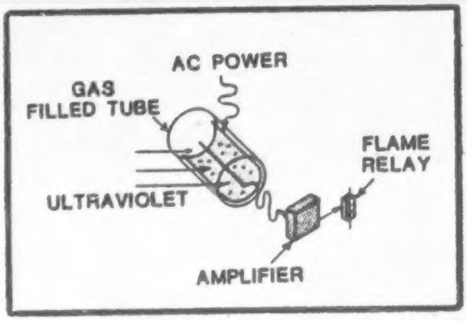

AC POWER
GAS FILLED TUBE
FLAME RELAY
ULTRAVIOLET
AMPLIFIER

Figure 26.
Ultraviolet Detector.

FLAME RECTIFICATION

A gas flame conducts electricity with a typical resistance of 50 kΩ to 150 kΩ. If the area of one electrode is much smaller than the other, the flame will conduct in one direction (similar to the ultraviolet cell). The flame rectification system (Figure 27) consists of flat metal plates welded to the pilot nozzle at ground electrical potential. If a gas flame is present, the rectified d.c. closes the flame relay, and the main burner may be turned ON. The conduction of an a.c. signal indicates that the flame rod is shorted. This will turn OFF the flame relay. The pilot flame is usually turned OFF after the main burner ignites.

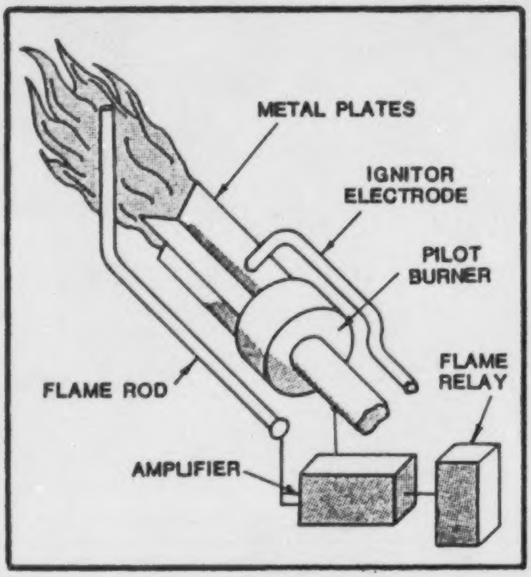


Figure 27. Flame Rectification System.

COMBUSTION CONTROL

Combustion control in both gas-fired and oil-fired boilers is accomplished by a motor that drives the combustion air damper and the fuel flow valve (Figure 28). The motor may be either a two position motor or a modulating motor depending on boiler size and design.

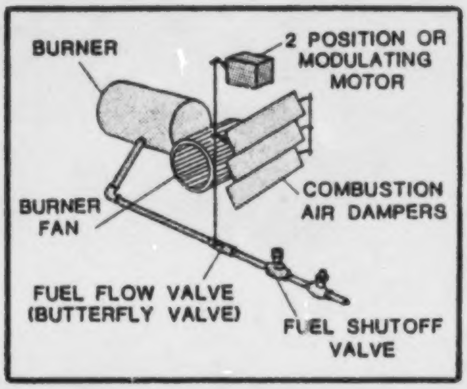

BURNER
2 POSITION OR MODULATING MOTOR
COMBUSTION AIR DAMPERS
BURNER FAN
FUEL FLOW VALVE (BUTTERFLY VALVE)
FUEL SHUTOFF VALVE

Figure 28.
Combustion Control.

TURN ON

The following sequence of steps is used to turn the boiler burner ON:

1. With the fuel shutoff valve closed, the air dampers are opened to the "high-fire" position, and the blower motor is turned ON. The timing control allows time for four air changes in the combustion chamber to remove any fuel vapors.
2. The air dampers are partially closed to the "low-fire" position.
3. The ignitor is turned ON, and fuel is admitted. In oil burners, the main burner ignites at low-fire; and the presence of the flame is detected before the burner is turned to high-fire. In gas burners, the pilot flame is lit and verified before the main burner fuel shut-off valve is opened.

4. After flame verification, the burner is adjusted to the high-fire condition.

TURN OFF

The following sequence of steps is used to turn the boiler burner OFF:

1. The fuel supply is turned OFF at the main shutoff valve.
2. The air dampers are partially closed to the low-fire position. The blower continues to operate, driving fuel vapors from the combustion chamber and flue tubes.
3. After four air changes, the blower is turned OFF and the air dampers are closed.

FIRING RATE CONTROL

Boiler controls are designed to maintain boiler pressure between two limits. Four types of firing rate controls are used, depending primarily upon boiler size.

On-Off

Many small boilers, including most cast iron boilers, emoloy a simple ON-OFF control system. There is no provision in the control system for a low-fire condition. The main burner turns ON when the boiler pressure falls below a lower limit and turns OFF when an upper limit is reached.

On-Off, Low Fire Start

Boilers in the 15 to 60 horsepower range often employ a low-fire ignition sequence but provide no modulation after the burner is ON at high-fire. The burner turns OFF when the upper pressure limit is reached.

High-Low

Boilers in the 60 to 150 horsepower range also employ a low-fire ignition sequence. The main burner then operates at high-fire until an intermediate pressure is reached. At this pressure the burner returns to low fire. If the pressure increases above the upper limit, the burner shuts OFF. If the pressure drops below the intermediate value, the burner goes to high-fire.

Modulating

Boilers larger than 150 horsepower usually use modulating control. The two-position control motor is replaced by a modulating motor that can vary the combustion rate continuously over a wide range. This control system is used for boiler control in electrical generating plants and in most other large boilers.

EXERCISES

1. State the boiler type most likely used in the following applications:
    - a. Production of low pressure steam for heating (installed in a small equipment room).
    - b. Production of steam for electrical power generation.
    - c. Production of 150 psi steam in an industrial plant.
2. Draw and label a diagram of a 3-pass Scotch marine boiler showing the following parts:
    - a. Combustion tube.
    - b. Flue tubes.
    - c. Rear header.
    - d. Front header.
    - e. Smoke box.
    - f. Burner.
3. Describe the function and operation of a blow-down tank.
4. Describe the burners used with the following fuels:
    - a. Natural gas.
    - b. Light fuel oils only.
    - c. Heavy fuel oils.
5. Draw and label diagrams of the following gas trains:
    - a. Pilot gas control.
    - b. UL.
    - c. FM.
    - d. FIA.
6. Describe the three flame safeguard systems used with boilers.

7. Describe the control sequence for the turn ON and turn OFF of a gas-fired boiler with high-low control.
8. Describe the difference in operation of recirculating and non-recirculating oil burner nozzles.

LABORATORY MATERIALS

Notebook or clipboard.

Pen or pencil.

Notes from labs in Modules HC-02, "System Types," and HC-03, "Refrigeration Equipment."

LABORATORY PROCEDURES

This laboratory consists of the third of four field trips to a large heating and air-conditioning installation. The system chosen should produce low pressure steam in a Scotch marine boiler. The purpose of this visit is a detailed study of the boiler.

1. Observe the boiler components, piping, and controls during the boiler explanation and tour. Record in the field notebook the data specified in the data table, as well as any other information available concerning the boiler.
2. Sketch the following components in the field notebook:
   a. Boiler shell, headers, smoke box, and location of water and steam ports.
   b. Fuel delivery system.
   c. Water level control system.

    - d. Blow-down tank.
    - e. Combustion air blower.
3. After completion of the field trip, draw diagrams showing the following:
    - a. A side-view cross section of the boiler showing the burner, combustion chamber, flue tubes, headers, and smoke box.
    - b. The fuel control system of the boiler.
    - c. The burner used in the boiler (if possible).
    - d. The flame safeguard system (if possible).
4. Write a description of the controls used for the following.
    - a. Turn ON.
    - b. Turn OFF.
    - c. Firing rate control.

DATA TABLE

DATA TABLE

1. Boiler type (and number of passes): __________
2. Steam Pressure: __________
3. Steam Delivery Rate: __________
4. Fuel: __________
5. Burner type: __________
6. Fuel train: __________
7. Flame detector system: __________

8. List details of control for the following:
   a. Turn ON.

   b. Turn OFF.

   c. Firing rate control.

9. Answer the following questions:
   a. How often are the flue tubes cleaned? Why?

   b. How often is the boiler "blown down"? Why?

   c. What kind of routine maintenance is performed on the boiler and how often?

   d. What problems have arisen in the operation of the boiler?

REFERENCES

Howell, Ronald H., and Sauer, Harry J., Jr. Environmental Control Principles. New York: American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc., 1978.

The Trane Co. Boilers for Steam and Hot Water. La Crosse, WI: The Trane Company Educational Division, 1971.

TEST

1. Water-tube boilers ...
    - a. are mainly used for electrical power production.
    - b. can operate at steam pressures of 5000 psi.
    - c. are not widely used in heating applications.
    - d. All of the above are true statements.
    - e. Only a and c are true statements.
2. Cast iron boilers ...
    - a. can be erected in cramped spaces – one section at a time.
    - b. are usually less expensive than fire-tube boilers.
    - c. are more efficient than small fire-tube boilers.
    - d. All of the above are true statements.
    - e. Only a and c are true statements.
3. Scotch marine boilers ...
    - a. are fire-tube boilers.
    - b. operate at pressures in the range of 15 to 250 psi.
    - c. are the most common boilers in heating service.
    - d. All of the above are true statements.
    - e. Only a and c are true statements.
4. The major advantage of a dry-back boiler over a wet-back boiler is that ...
    - a. the dry-back boiler is more efficient.
    - b. the dry-back boiler is smaller and weighs less.
    - c. the flue tubes of the wet-back boiler are not easily accessible for servicing.
    - d. the dry-back boiler uses less refractory material.
5. The mechanical atomizing oil burner ...
    - a. consists of a cup that spins in an air stream.
    - b. burns lightweight fuel oils.
    - c. burns heavy fuel oils.

d. All of the above are true statements.
e. Only a and b are true statements.

6. The most popular burner for heavier oils is ...
   a. the mechanical atomizing burner.
   b. the air or steam atomizing burner.
   c. the horizontal rotary burner.
   d. the ring burner.
7. Which of the following is not a part of all three approved gas control systems?
   a. Pilot solenoid valve.
   b. Butterfly modulating gas valve.
   c. Safety solenoid shutoff valve.
   d. Automatic motorized gas valve.
   e. All are included in all systems.
8. If a gas train has a vent to the atmosphere between the two automatic shutoff valves in the main burner gas supply, it is probably approved by ...
   a. UL.
   b. FM.
   c. FIA.
   d. FBI.
9. Infrared flame detectors ...
   a. are used with oil fires only.
   b. send a d.c. signal to an amplifier, indicating the presence of a flame.
   c. can be fooled by electric ignitor sparks.
   d. are used in residential oil burners only.
   e. None of the above is a true statement.
10. Flame rectification flame detectors ...
   a. produce a d.c. signal when the flame is present.
   b. produce an a.c. signal when the flame rod is shorted.

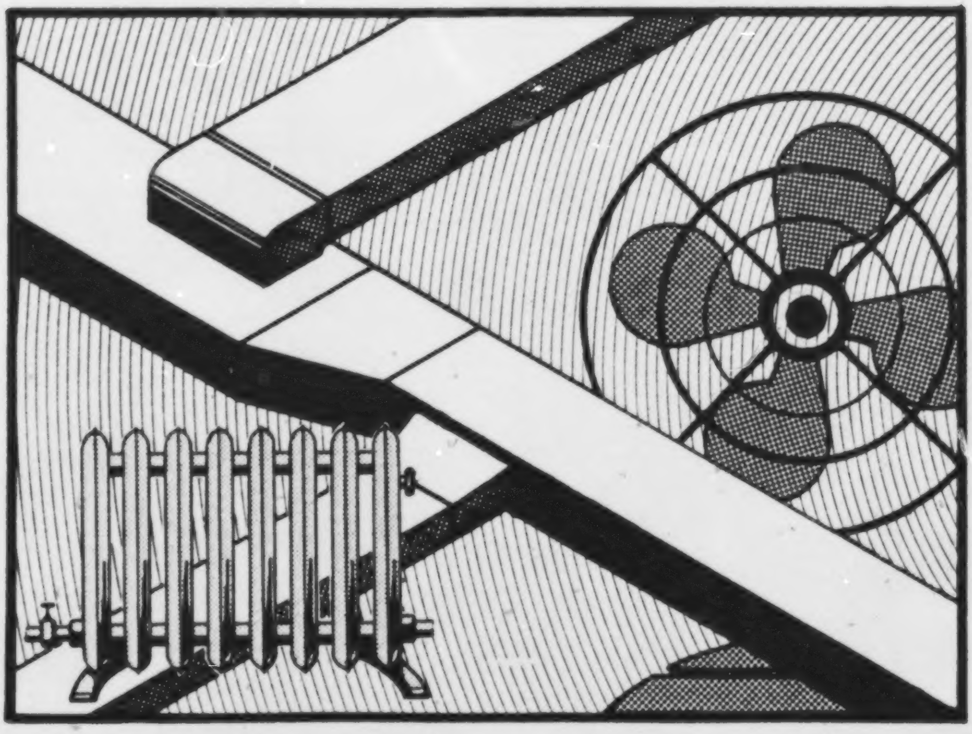
c. produce no signal when no flame is present.
d. All of the above are true statements.
e. None of the above is a true statement.

11. In a gas-fired boiler the pilot flame ...
    a. is lit when the combustion air blower is turned ON.
    b. must be detected before the main burner gas valve can open.
    c. burns continuously during main burner operation.
    d. Both a and b are true statements.
    e. Both b and c are true statements.

ENERGY TECHNOLOGY

CONSERVATION AND USE

HEATING, VENTILATING, AND AIR CONDITIONING



MODULE HC - 06

PIPING

CORD CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

INTRODUCTION

At first glance, it may seem that piping is a simple matter of connecting two points with a piece of pipe large enough to carry fluid from one place to another. However, piping design in air conditioning and heating systems requires care in selecting and assembling the components of a sophisticated system. Major problems often arise because of failures in the piping system. Improper piping is a major cause of loss of capacity and efficiency in air conditioning systems.

This module discusses the sizing of water pipes and pumps and the sizing of pipes in refrigerant systems. It also presents common problems that should be avoided in pipe design and construction. In the laboratory, the student will practice techniques used in soldering and brazing copper pipes for air conditioning systems.

PREREQUISITES

The student should have completed Modules HC-03, "Refrigeration Equipment," and HC-05, "Boilers for Heating Applications."

OBJECTIVES

Upon completion of this module, the student should be able to:

1. List the piping materials commonly used in air conditioning and heating applications.

2. Draw diagrams of expansion loops for risers and explain their application.
3. Explain the operation and application of the following valve types:
    a. Globe.
    b. Angle.
    c. Y.
    d. Gate.
    e. Swing check.
    f. Lift check.
4. Describe the following water piping systems with the use of diagrams and state the application of each system:
    a. Reverse return.
    b. Reverse return headers with direct return risers.
    c. Direct return.
5. Given the water flow rate and schematic diagram of a water piping system and charts in the subject matter, determine the pipe size and pump capacity required.
6. Explain the effects of the presence of refrigeration oil on the design of the following pipes:
    a. Hot gas line.
    b. Suction line.
    c. Liquid line.
7. Given the refrigeration load, the equivalent length of each pipe, and charts in the subject matter, determine the proper pipe sizes for a refrigeration system.
8. Discuss the features necessary for the following pipes to assure proper system operation:
    a. Hot gas line.
    b. Suction line.
    c. Liquid line.

9. Explain the connections necessary when two or more compressors are used in one refrigeration system.
10. Draw diagrams showing the operation of the following steam pipes:
    a. Dripped riser.
    b. Non-dripped riser.
11. Explain the operation of the following steam traps:
    a. Float trap.
    b. Thermostatic trap.
12. List the five types of steam systems and the pressure ranges of each.
13. Given the proper equipment, braze and solder copper tubing in the laboratory.

GENERAL PIPING DESIGN

PIPE TYPES AND APPLICATIONS

Several types of piping and tubing may be used in air conditioning and heating systems. Although aluminum and plastic pipes are sometimes used, most piping is copper or steel. Fittings are usually of copper, brass, or iron. Table 1 lists the types of pipe and fittings suitable for air conditioning and heating applications.

Copper tubing and pipe are available in several types. Annealed copper tubing is soft and easily bent; it is used primarily in residential systems and is joined using solder. Hard copper is used extensively in larger systems and cannot be bent; it is connected with fittings that are brazed to the tubing. Both types are available in three wall thicknesses designated K, L, and M. K is the thickest wall, and is used for higher pressures. M is thin-walled tubing, and is used primarily for drainage and other nonpressure applications. Most air conditioning applications use type L copper tubing. All copper tubing used in air conditioning is designated ACR tubing and should not be confused with copper tubing used in plumbing applications, called nominal tubing.

Steel pipe also is available in several wall thicknesses. Most air conditioning applications use schedule 40 steel pipe, although thicker wall pipe is sometimes used for high pressure steam piping.

TABLE 1. RECOMMENDED PIPE AND FITTING MATERIALS FOR VARIOUS SERVICES.

SERVICE		PIPE	FITTINGS
REFRIGERANTS 12, 22, 500 and 502	Suction Line	Hard copper tubing, Type L*	Wrought copper, wrought brass or tinned cast brass
		Steel pipe, standard wall Lap welded or seamless	150 lb welding or threaded malleable iron
	Liquid Line	Hard copper tubing, Type L*	Wrought copper, wrought brass or tinned cast brass
		Steel pipe, standard wall Lap welded or seamless	300 lb welding or threaded malleable iron
	Hot Gas Line	Hard copper tubing, Type L*	Wrought copper, wrought brass or tinned cast brass
		Steel pipe, standard wall Lap welded or seamless	300 lb welding or threaded malleable iron
CHILLED WATER		Black or galvanized steel pipe†	Welding, galvanized; cast, malleable or black iron‡
		Hard copper tubing†	Cast brass, wrought copper or wrought brass
CONDENSER OR MAKE-UP WATER		Galvanized steel pipe†	Welding, galvanized; cast or malleable iron‡
		Hard copper tubing†	Cast brass, wrought copper or wrought brass
DRAIN OR CONDENSATE LINES		Galvanized steel pipe†	Galvanized drainage; cast or malleable iron‡
		Hard copper tubing†	Cast brass, wrought copper or wrought brass
STEAM OR CONDENSATE		Black steel pipe†	Welding or cast iron‡
		Hard copper tubing†	Cast brass, wrought copper or wrought brass
HOT WATER		Black steel pipe	Welding or cast iron‡
		Hard copper tubing†	Cast brass, wrought copper or wrought brass

*Except for sizes 1/4" and 3/8" OD where all thicknesses of 0.30" and 0.32" are required. Soft copper refrigeration tubing may be used for sizes 1-3/8" OD and smaller. Mechanical joints must not be used with soft copper tubing in sizes larger than 7/8" OD.

†Normally standard wall steel pipe or Type M hard copper tubing is satisfactory for air conditioning applications. However, the piping material selected should be checked for the design temperature-pressure ratings.

‡Normally 125 lb cast iron and 150 lb malleable iron fittings are satisfactory for the usual air conditioning application. However, the fitting material selected should be checked for the design temperature-pressure ratings.

PIPE SUPPORTS

Pipe must be supported along its length to prevent sagging. This is due to the weight of the pipe and the fluid it contains. Tables 2 and 3 give the recommended support spacings for schedule 40 steel pipe and hard copper pipe. Support structures must also reduce the transmission of vibrations and allow for the expansion of the pipe as the temperature changes.

TABLE 2. RECOMMENDED SUPPORT SPACING FOR SCHEDULE 40 PIPE.

Nominal Pipe Size (inches)	Distance Between Supports (feet)
3/4 - 1 1/4	8
1 1/2 - 2 1/2	10
3 - 3 1/2	12
4 - 6	14
8 - 12	16
14 - 24	20

TABLE 3. RECOMMENDED SUPPORT SPACING FOR COPPER TUBING.

Tube OD (inches)	Distance Between Supports (feet)
- 5/8	6
7/8 - 1 1/8	8
1 3/8 - 2 1/8	10
2 5/8 - 5 1/8	12
6 1/2 - 8 1/8	14

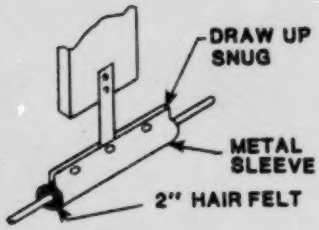


Figure 1. Isolated Sheath Pipe Hanger.

Figure 1 shows an isolated sheath pipe hanger used to reduce the vibration transmitted from the pipe to the building structure. This type of hanger is used in piping systems incorporating machinery such as pumps and compressors.

In most systems, allowances must be made for the expansion of the pipe as its temperature changes. Expansion joints of several types may be employed. Slip-type joints consist of telescoping pipe sections. They have the disadvantages of requiring packing and lubrication and guides to prevent binding of the joint. Bellows-type expansion joints are satisfactory for short travels and moderate pressures. Longer lengths must be supported, and high pressure stiffens the bellows and reduces its vibration isolation characteristics.

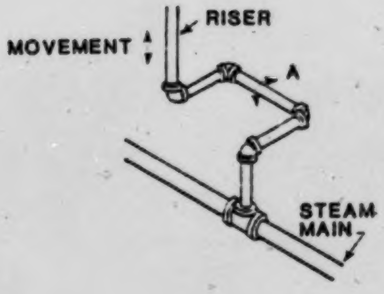
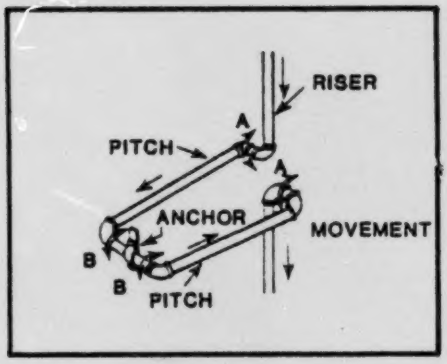


Figure 2. Riser Connected to Allow for Expansion.

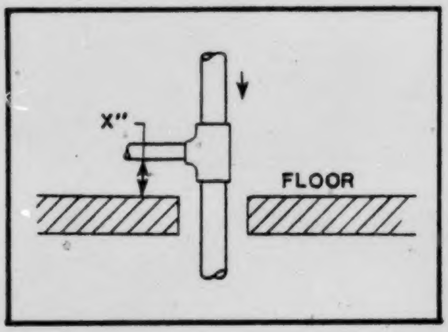
Vertical pipes, called risers, are anchored at one end only and are equipped with expansion loops. Figure 2 shows the loop used to connect a riser to a fixed horizontal pipe. In this case, the riser is anchored at the top. For heights of five stories or more, expansion loops must be included in the length of the risers. Figure 3 shows the combination of expansion loop and riser anchor used for this.

Figure 3. Riser Anchor.



If horizontal takeoff pipes are located too close to the floor or ceiling (Figure 4), the expansion of the riser may bring the horizontal pipe in contact with the obstruction and result in a break.

Figure 4. Takeoff Too Close to Floor.



VALVE TYPES AND APPLICATIONS

A wide variety of valves are used in air conditioning and heating applications. The basic types are discussed here.

Figures 5, 6, and 7 shows respectively a globe valve, a Y valve, and an angle valve. Many variations of these types are available, but all serve the same basic function.

Their high resistance to fluid flow, even when fully opened, makes them unsuited for applications requiring only ON-OFF operation.

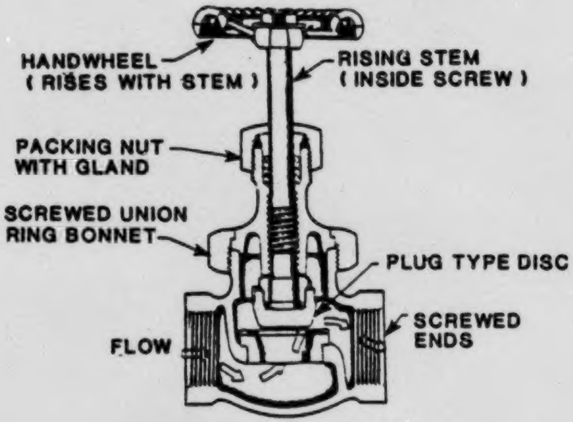

HANDWHEEL (RISES WITH STEM)
RISING STEM (INSIDE SCREW)
PACKING NUT WITH GLAND
SCREWED UNION RING BONNET
PLUG TYPE DISC
SCREWED ENDS
FLOW

Figure 5. Glove Valve.

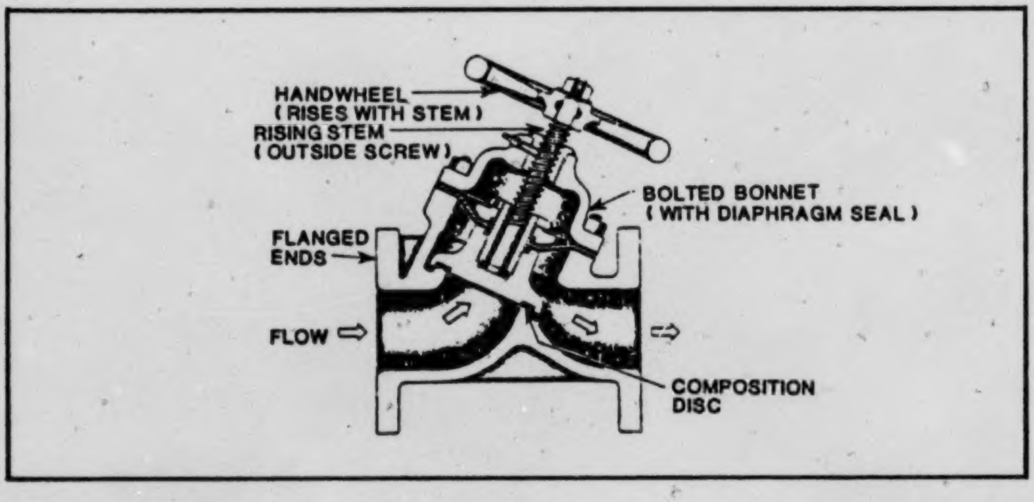

HANDWHEEL (RISES WITH STEM)
RISING STEM (OUTSIDE SCREW)
BOLTED BONNET (WITH DIAPHRAGM SEAL)
FLANGED ENDS
FLOW
COMPOSITION DISC

Figure 6. Y Valve (Diaphragm Type).

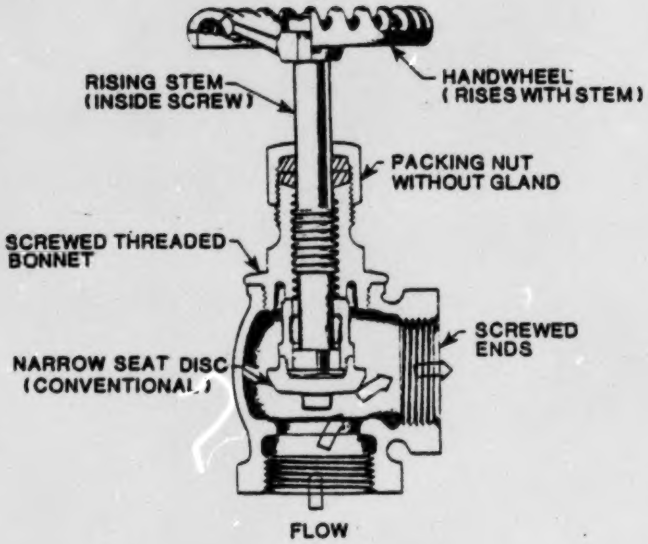

RISING STEM (INSIDE SCREW)
HANDWHEEL (RISES WITH STEM)
PACKING NUT WITHOUT GLAND
SCREWED THREADED BONNET
SCREWED ENDS
NARROW SEAT DISC (CONVENTIONAL)
FLOW

Figure 7. Angle Valve.

Figure 8 shows a gate valve. This type of valve consists of a wedge-shaped gate that may be lowered into the fluid stream to block flow. It is not suited for flow control, but does present the minimum resistance to flow when in the fully-opened position.

Check valves are used to allow fluid flow in one direction while preventing flow in the opposite direction. Swing check valves (Figure 9) may be used in a horizontal line or in a vertical line for upward flow. The valve disc swings upward out of the fluid path to present little resistance to flow in one direction, but drops by gravity to block flow in the reverse direction. Swing check valves are usually used in conjunction with gate valves.

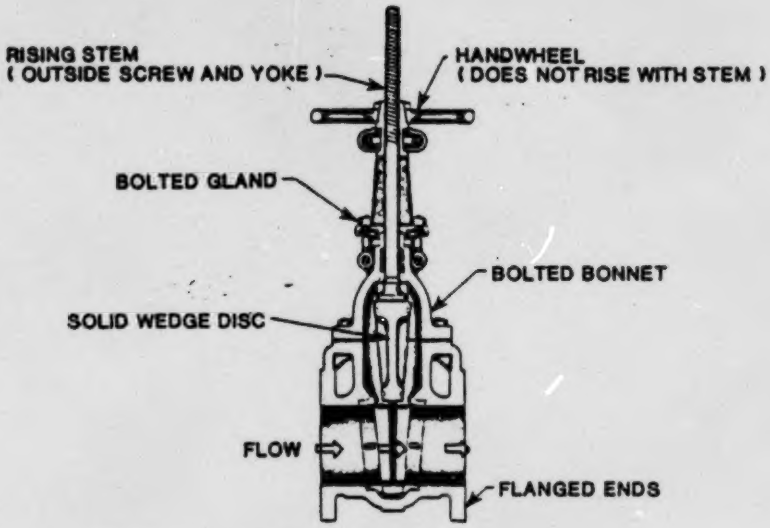

RISING STEM
(OUTSIDE SCREW AND YOKE)
HANDWHEEL
(DOES NOT RISE WITH STEM)
BOLTED GLAND
BOLTED BONNET
SOLID WEDGE DISC
FLOW
FLANGED ENDS

Figure 8. Gate Valve (Rising Stem).

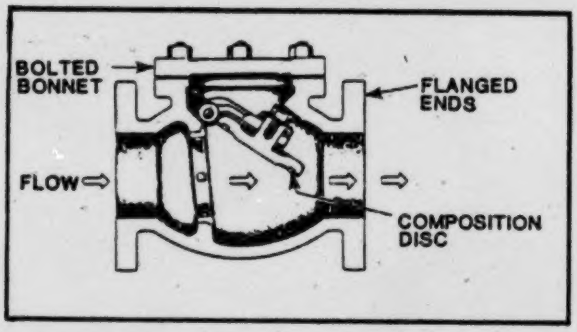

BOLTED BONNET
FLANGED ENDS
FLOW
COMPOSITION DISC

Figure 9. Swing Check Valve.

Lift valves (Figure 10) are similar in design to glove valves and also close by gravity. They can be used in horizontal pipes only and are usually used with globe, Y, or angle valves. The resistance of various valves to fluid flow is given in Table 4 in the following section.

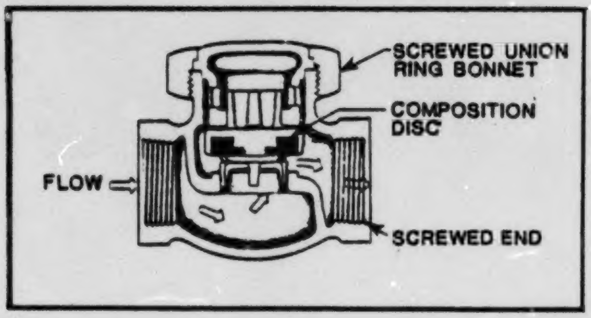


Figure 10. Lift Check Valve.

PRESSURE LOSSES IN VALVES AND FITTINGS

Fittings are responsible for a large part of the pressure drop in most piping systems. The greatest pressure drops occur when the fluid changes directions. Sharper turns produce greater loss. For this reason, long radius elbows are used whenever possible, and 45° ells are preferred over 90° ells if space permits. Figure 11 illustrates one circumstance in which the use of 45° ells can greatly reduce the pressure drop in the pipe and, thus, the pump power required to move fluid through the system.

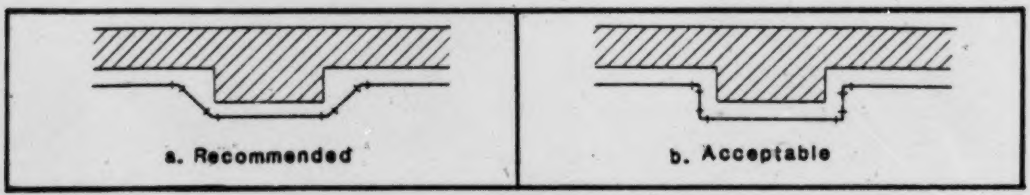

a. Recommended
b. Acceptable

Figure 11. Offsets to Avoid Obstructions.

Tees should be installed in the piping system in a manner that produces the minimum turbulence. Figure 12 shows the right and wrong ways to connect tees. A condition called

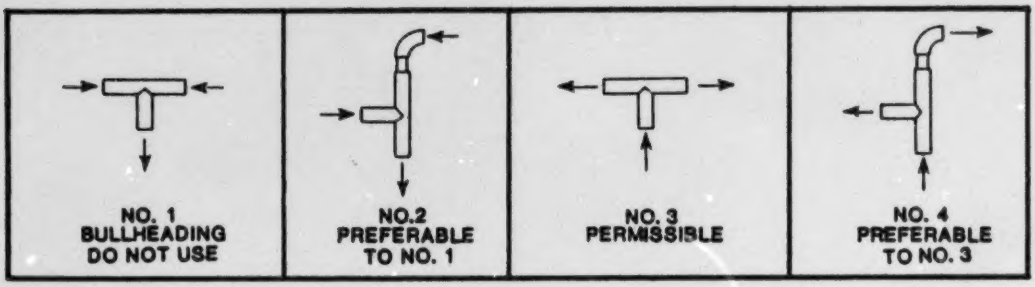

NO. 1
BULLHEADING
DO NOT USE
NO.2
PREFERABLE
TO NO. 1
NO. 3
PERMISSIBLE
NO. 4
PREFERABLE
TO NO. 3

Figure 12. Tees.

bullheading occurs whenever flow is into the straight portion of the tee from both directions. Bullheading produces great turbulence and should always be avoided.

When one fluid line joins another, the resistance to flow can be reduced by connecting the entering line at a sharp angle in the direction of flow, as shown in Figure 13.

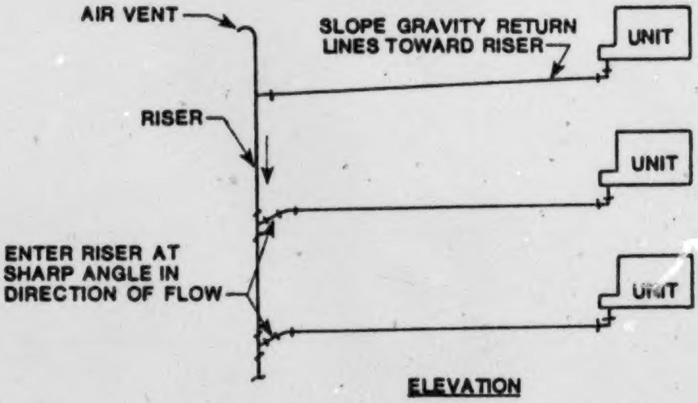

AIR VENT
SLOPE GRAVITY RETURN
LINES TOWARD RISER
UNIT
RISER
UNIT
ENTER RISER AT
SHARP ANGLE IN
DIRECTION OF FLOW
UNIT
ELEVATION

Figure 13. Connecting Entering Line to Reduce Resistance to Flow.

The amount of resistance to fluid flow presented by a valve or fitting is specified in terms of the length of straight pipe of the same size that has the same resistance.

Tables 4, 5, and 6 list the resistances of standard valves and fittings for commonly used pipe sizes. Refer to these tables and compare the values for various types of valves and fittings. The total resistance of a piping system is expressed in equivalent feet, and is the sum of the equivalent feet for each component and the length of all pipes in the system. These tables will be used in example problems later in this module.

TABLE 4. VALVE LOSSES IN EQUIVALENT FEET OF PIPE*.

NOMINAL PIPE OR TUBE SIZE (in.)	GLOBE†	60°-Y	45°-Y	ANGLE†	GATE††	SWING CHECK‡	Y-TYPE STRAINER‡‡		LIFT CHECK
							Flanged End	Screwed End	
3/8	17	8	6	6	0.6	5	—	—	Globe & Vertical Lift Same as Globe Valve**
1/2	18	9	7	7	0.7	6	—	3	
3/4	22	11	9	9	0.9	8	—	4	
1	29	15	12	12	1.0	10	—	5	
1¼	38	20	15	15	1.5	14	—	9	
1½	43	24	18	18	1.8	16	—	10	
2	55	30	24	24	2.3	20	27	14	
2½	69	35	29	29	2.8	25	28	20	
3	84	43	35	35	3.2	30	42	40	
3½	100	50	41	41	4.0	35	48	—	
4	120	58	47	47	4.5	40	60	—	
5	140	71	58	58	6	50	80	—	
6	170	88	70	70	7	60	110	—	
8	220	115	85	85	9	80	150	—	
10	280	145	105	105	12	100	190	—	
12	320	165	130	130	13	120	250	—	Angle Lift Same as Angle Valve
14	360	185	155	155	15	135	—	—	
16	410	210	180	180	17	150	—	—	
18	460	240	200	200	19	165	—	—	
20	520	275	235	235	22	200	—	—	
24	610	320	265	265	25	240	—	—	

*Losses are for all valves in fully open position and strainers clean.

†These losses do not apply to valves with needle point type seats.

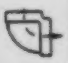
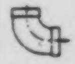
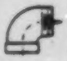
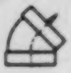
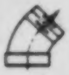
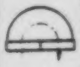
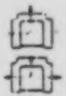
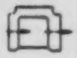
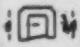
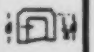
‡Losses also apply to the in-line, ball type check valve.

**For "Y" pattern globe lift check valve with seat approximately equal to the nominal pipe diameter, use values of 60° "Y" valve for loss.

††Regular and short pattern plug cock valves, when fully open, have same loss as gate valve. For valve losses of short pattern plug cocks above 6 ins. check manufacturer.

‡‡For .045 thru 3/16 in. perforations with screens 50% clogged, loss is doubled.

TABLE 5. FITTING LOSSES IN EQUIVALENT FEET OF PIPE.

NOMINAL PIPE OR TUBE SIZE (in.)	SMOOTH BEND ELBOWS						SMOOTH BEND TEES			
								Straight-Thru Flow		
	90° Std* 	90° Long Rad.† 	90° Street* 	45° Std* 	45° Street* 	180° Std* 	Flow-Thru Branch 	No Reduction 	Reduced ¼ 	Reduced ½ 
⅜	1.4	0.9	2.3	0.7	1.1	2.3	2.7	0.9	1.2	1.4
½	1.6	1.0	2.5	0.8	1.3	2.5	3.0	1.0	1.4	1.6
¾	2.0	1.4	3.2	0.9	1.6	3.2	4.0	1.4	1.9	2.0
1	2.6	1.7	4.1	1.3	2.1	4.1	5.0	1.7	2.3	2.6
1¼	3.3	2.3	5.6	1.7	3.0	5.6	7.0	2.3	3.1	3.3
1½	4.0	2.6	6.3	2.1	3.4	6.3	8.0	2.6	3.7	4.0
2	5.0	3.3	8.2	2.6	4.5	8.2	10	3.3	4.7	5.0
2½	6.0	4.1	10	3.2	5.2	10	12	4.1	5.6	6.0
3	7.5	5.0	12	4.0	6.4	12	15	5.0	7.0	7.5
3½	9.0	5.9	15	4.7	7.3	15	18	5.9	8.0	9.0
4	10	6.7	17	5.2	8.5	17	21	6.7	9.0	10
5	13	8.2	21	6.5	11	21	25	8.2	12	13
6	16	10	25	7.9	13	25	30	10	14	16
8	20	13	—	10	—	33	40	13	18	20
10	25	16	—	13	—	42	50	16	23	25
12	30	19	—	16	—	50	60	19	26	30
14	34	23	—	18	—	55	68	23	30	34
16	38	26	—	20	—	62	78	26	35	38
18	42	29	—	23	—	70	85	29	40	42
20	50	33	—	26	—	81	100	33	44	50
24	60	40	—	30	—	94	115	40	50	60

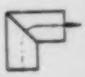
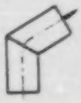
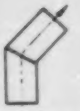
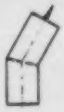
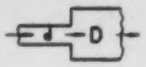
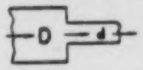
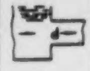
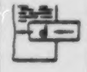
NOMINAL PIPE OR TUBE SIZE (in.)	MITRE ELBOWS			
	90° Ell 	60° Ell 	45° Ell 	30° Ell 
⅜	2.7	1.1	0.6	0.3
½	3.0	1.3	0.7	0.4
¾	4.0	1.6	0.9	0.5
1	5.0	2.1	1.0	0.7
1¼	7.0	3.0	1.5	0.9
1½	8.0	3.4	1.8	1.1
2	10	4.5	2.3	1.3
2½	12	5.2	2.8	1.7
3	15	6.4	3.2	2.0
3½	18	7.3	4.0	2.4
4	21	8.5	4.5	2.7
5	25	11	6.0	3.2
6	30	13	7.0	4.0
8	40	17	9.0	5.1
10	50	21	12	7.2
12	60	25	13	8.0
14	68	29	15	9.0
16	78	31	17	10
18	85	37	19	11
20	100	41	22	13
24	115	49	25	16

TABLE 6. SPECIAL FITTING LOSSES IN EQUIVALENT FEET OF PIPE.

NOM. PIPE OR TUBE SIZE (In.)	SUDDEN ENLARGEMENT* d/D			SUDDEN CONTRACTION* d/D			SHARP EDGE*		PIPE PROJECTION*	
	¼	½	¾	¼	½	¾	Entrance	Exit	Entrance	Exit
										
⅜	1.4	0.8	0.3	0.7	0.5	0.3	1.5	.8	1.5	1.1
½	1.8	1.1	0.4	0.9	0.7	0.4	1.8	1.0	1.8	1.5
¾	2.5	1.5	0.5	1.2	1.0	0.5	2.8	1.4	2.8	2.2
1	3.2	2.0	0.7	1.6	1.2	0.7	3.7	1.8	3.7	2.7
1¼	4.7	3.0	1.0	2.3	1.8	1.0	5.3	2.6	5.3	4.2
1½	5.8	3.6	1.2	2.9	2.2	1.2	6.6	3.3	6.6	5.0
2	8.0	4.8	1.6	4.0	3.0	1.6	9.0	4.4	9.0	6.8
2½	10	6.1	2.0	5.0	3.8	2.0	12	5.6	12	8.7
3	13	8.0	2.6	6.5	4.9	2.6	14	7.2	14	11
3½	15	9.2	3.0	7.7	6.0	3.0	17	8.5	17	13
4	17	11	3.8	9.0	6.8	3.8	20	10	20	16
5	24	15	5.0	12	9.0	5.0	27	14	27	20
6	29	22	6.0	15	11	6.0	33	19	33	25
8	—	25	8.5	—	15	8.5	47	24	47	35
10	—	32	11	—	20	11	60	29	60	46
12	—	41	13	—	25	13	73	37	73	57
14	—	—	16	—	—	16	86	45	86	66
16	—	—	18	—	—	18	96	50	96	77
18	—	—	20	—	—	20	115	58	115	90
20	—	—	—	—	—	—	142	70	142	108
24	—	—	—	—	—	—	163	83	163	130

*Enter table for losses at smallest diameter "d."

WATER PIPING

SYSTEM TYPES

Most large air conditioning systems incorporate at least two water systems. One supplies chilled water from the chiller to the fan coils. The other moves warm water from the condenser to a cooling tower. These water systems may be operated as open or closed loops. An open system is one in which the units served, such as cooling towers, are all open to atmospheric pressure. In a closed system, the units supplied – such as fan coils – are sealed, and atmospheric pressure has no effect.

Whenever possible, closed systems are connected in an arrangement called reverse return piping as shown in Figure 14. In this system, several identical units are connected so that the total length of pipe to and from each unit is the same. The unit with the shortest supply run has the longest return run. Therefore, the flow rates through all units balance because each loop has the same resistance.

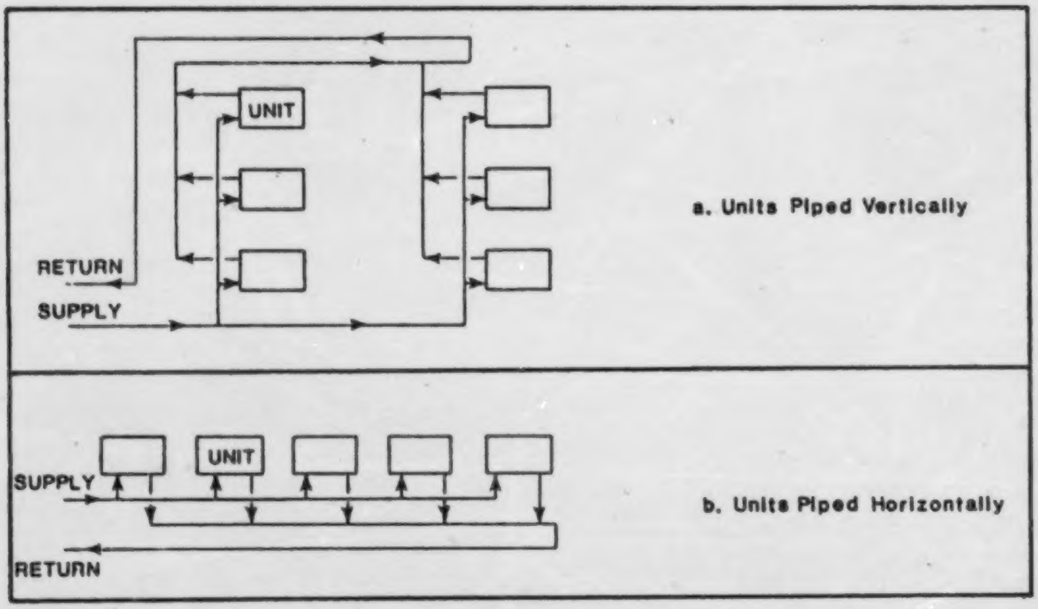

UNIT
RETURN
SUPPLY
a. Units Piped Vertically
SUPPLY
UNIT
RETURN
b. Units Piped Horizontally

Figure 14. Reverse Return Piping.

Figure 15 is a water system with reverse return headers and direct return risers. This is not a balanced system, since the units at the top of this figure have shorter piping runs than those at the bottom. However, the risers are

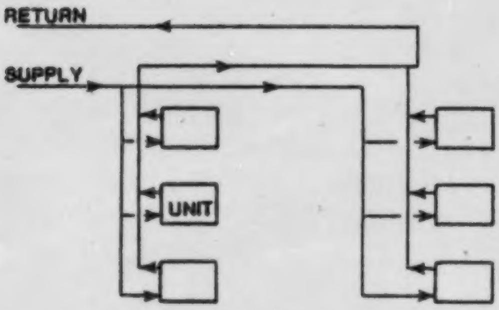


Figure 15. Reverse Return Headers With Direct Return Risers.

balanced because each has the same total loop resistance between the supply and return lines. When long piping runs are required, this system is often more economical than reverse return piping. If all units supplied are of the same fluid resistance, the system must be balanced by using different pipe sizes or by including balancing valves. This system is often used for fan coils of different sizes when different coil capacities help balance the system.

Figure 16 shows a direct return piping system in which each unit is connected to the supply and return mains by the shortest possible pipe. Direct return systems are used for closed water systems in which each unit requires balancing valves because of differing capacities. Open systems are always the direct return type because units that are open to atmospheric pressure require individual flow control, and the extra pipe length of the reverse return systems affords no advantages.

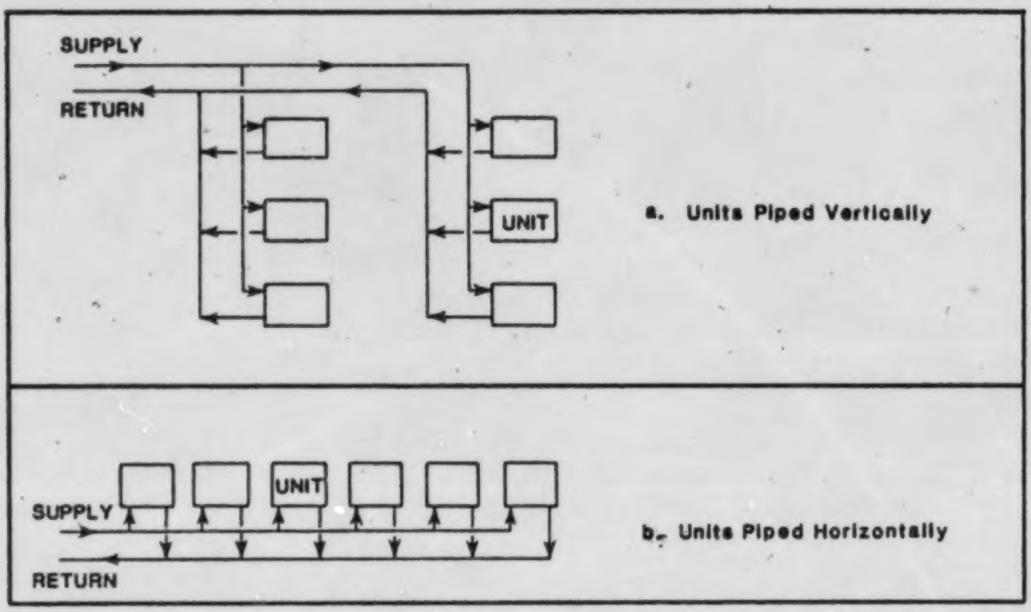

SUPPLY
RETURN
UNIT
a. Units Piped Vertically
UNIT
SUPPLY
RETURN
b. Units Piped Horizontally

Figure 16. Direct Return Water Piping System.

PUMP CONNECTIONS

Pipes bringing water to the pumps should always be arranged to minimize air entry into the pump and to bring the water into the pump in the plane of the pump rotor. Figure 17 illustrates correct pump connections and incorrect connections that can lower system efficiency. (Note that every wrong method mentioned in this module is actually found in some systems.)

Parts a, c, and d of this figure show connections that can result in air being drawn into the pump and correct connections that will remedy this problem. Figure 17b is a top view showing a water path out of the plane of the pump rotor and the necessary correction.

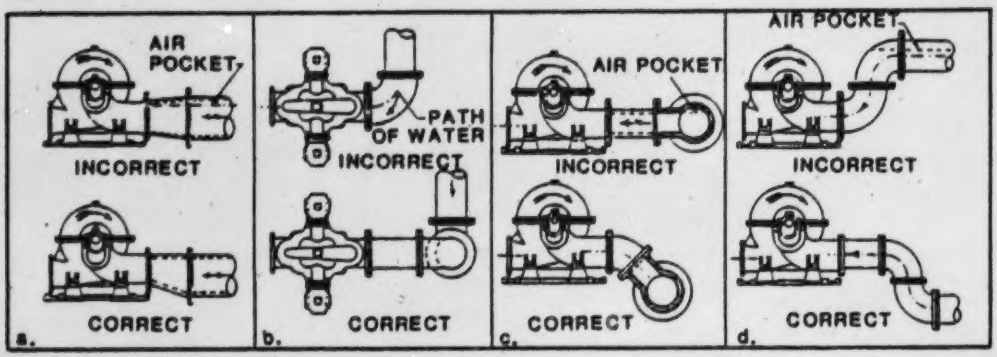

AIR POCKET
INCORRECT
CORRECT
a.
PATH OF WATER
INCORRECT
CORRECT
b.
AIR POCKET
INCORRECT
CORRECT
c.
AIR POCKET
INCORRECT
CORRECT
d.

Figure 17. Pump Suction Connections.

Figure 18 shows the piping and valve connections used when two or more pumps are used in the same water system.

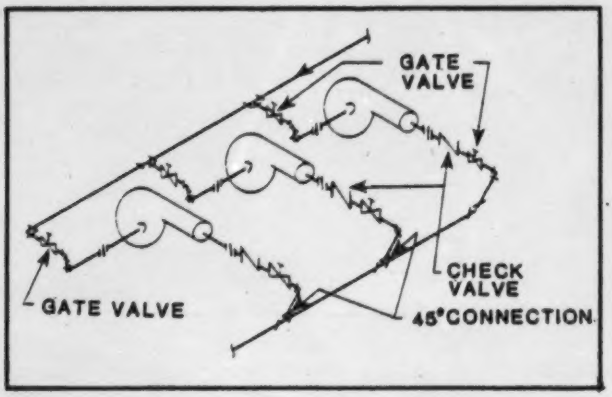
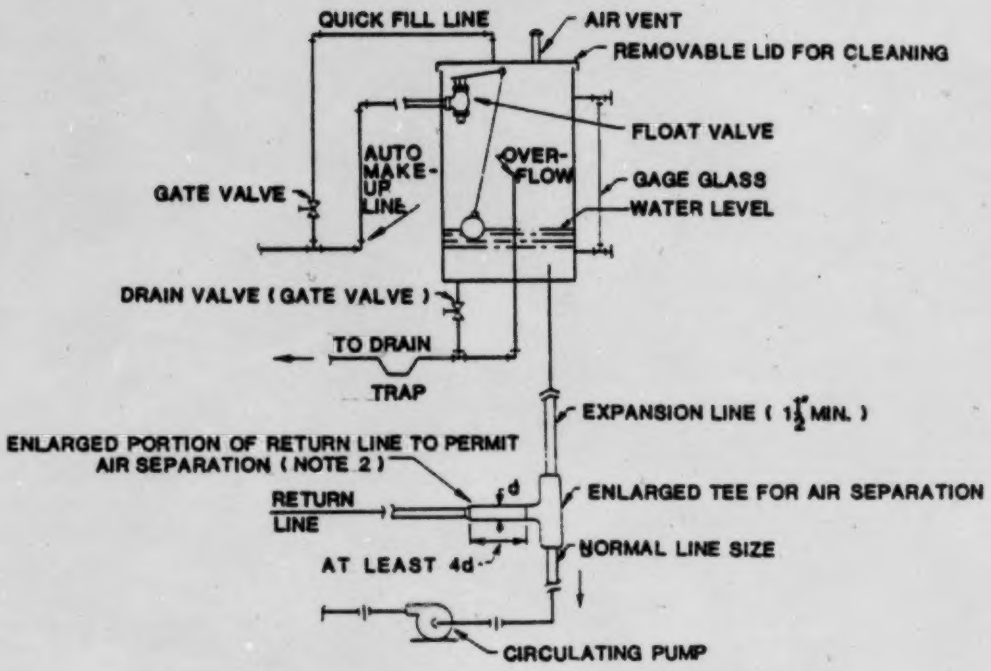

GATE VALVE
CHECK VALVE
45°CONNECTION
GATE VALVE

Figure 18. Multiple Pump Piping.

Closed water systems include an expansion tank to allow for expansion of the water as its temperature changes. This tank may be sealed, or left open to the atmosphere as shown in Figure 19. This is still a closed system, as this is the only opening to atmospheric pressure in the system. An enlarged tee is incorporated at the point of entry of the return line into the expansion line to remove any air bubbles


QUICK FILL LINE
AIR VENT
REMOVABLE LID FOR CLEANING
FLOAT VALVE
AUTO MAKE-UP LINE
OVER-FLOW
GATE VALVE
GAGE GLASS
WATER LEVEL
DRAIN VALVE (GATE VALVE)
TO DRAIN
TRAP
EXPANSION LINE (1½" MIN.)
ENLARGED PORTION OF RETURN LINE TO PERMIT AIR SEPARATION (NOTE 2)
d
RETURN LINE
ENLARGED TEE FOR AIR SEPARATION
NORMAL LINE SIZE
AT LEAST 4d
CIRCULATING PUMP

NOTES:

1. Do not put any valve strainer or trap in the expansion line.
2. Enlarged portion of return line and enlarged tee are each two standard pipe sizes larger than return line.

Figure 19. Open Expansion Tank Piping.

in the return water before these bubbles can reach the pump. Water strainers may be placed in the return line upstream from this point or in the discharge line from the pump. Strainers are never placed between the tee and the pump inlet since a clogged strainer can result in return water being diverted completely to the expansion tank. The pump would run dry and be destroyed.

PIPE AND PUMP SIZING

Water systems are usually designed to have a water velocity of not more than 15 feet per second (fps). Higher flow rates result in greater frictional losses. Higher flow rates also shorten the life of elbows in the system because of erosion. In general, larger pipes result in lower pump capacities and lowered operating costs. However, pipe cost is usually the greatest expense in any water system, especially in larger systems, and sizing pipes for flow rates below 5 fps is rare.

Figures 20 and 21 are charts used in sizing pipes and determining pump pressures for closed and open systems, respectively.

The vertical scale of these charts is the water flow rate in gallons per minute. The horizontal scale is the friction loss in feet of head of water per 100 feet of pipe. The slanted lines represent pipe size and water velocity in feet per second. Flow rates of greater than 15 fps and friction losses of greater than 10 feet/100 feet are not recommended. These are represented by shaded areas on the charts.

If any two of the quantities shown on the charts are known, the other two quantities may be read from the chart. Examples A and B illustrate use of these charts and Tables 4, 5, and 6 in determining pipe size and pump capacity in closed and open water systems.

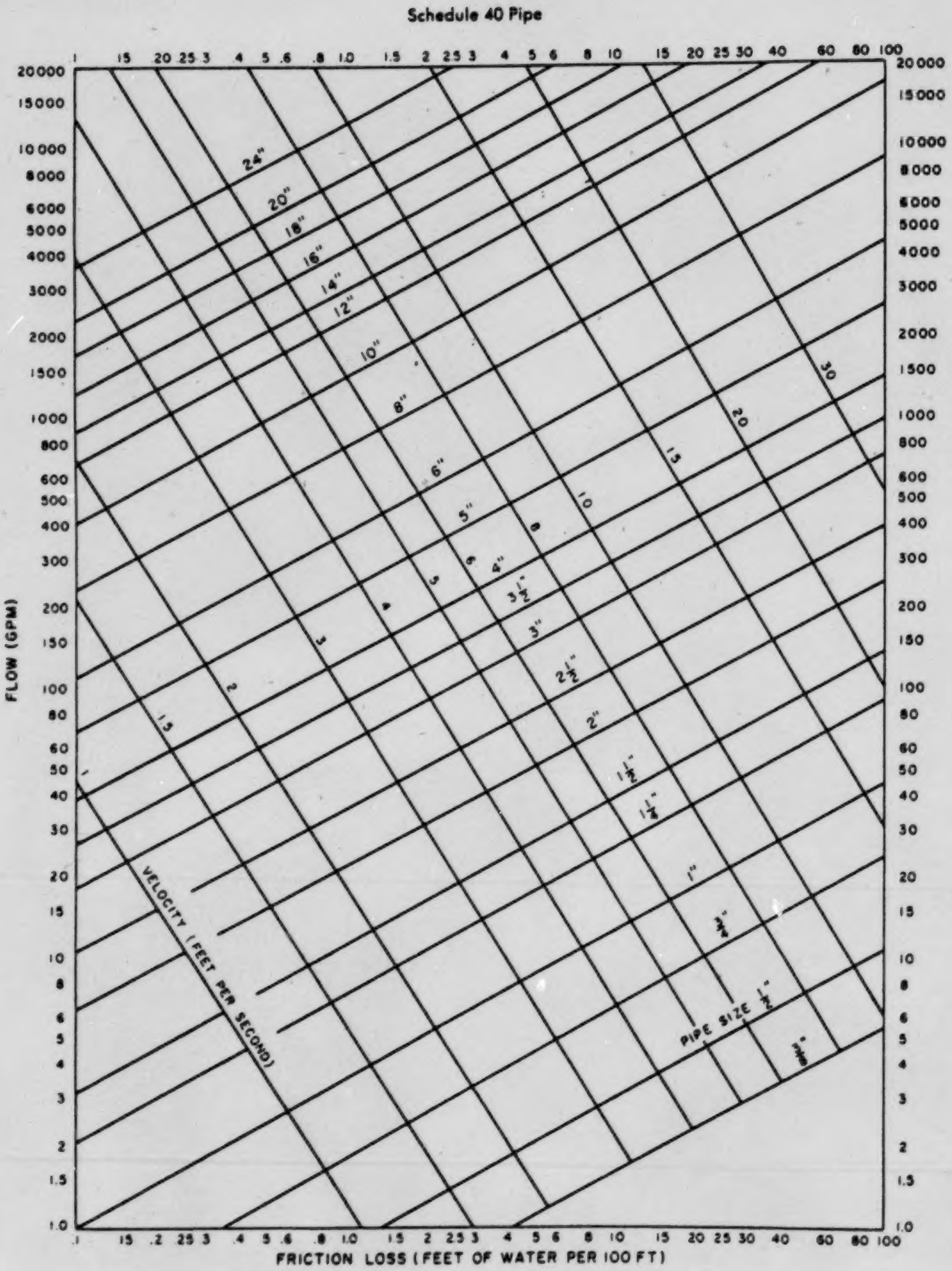


Figure 20. Friction Loss for Closed Piping Systems.

Schedule 40 Pipe

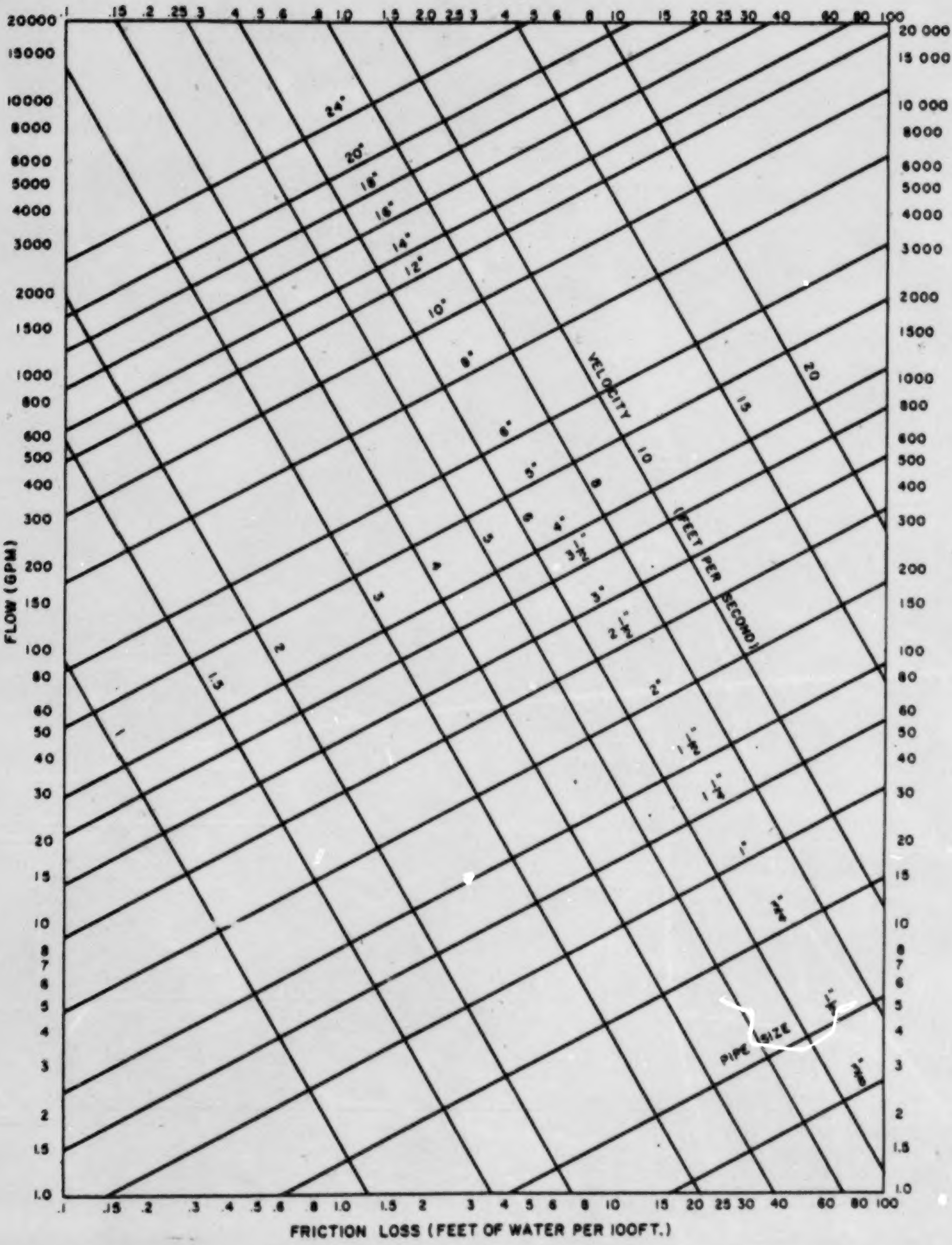
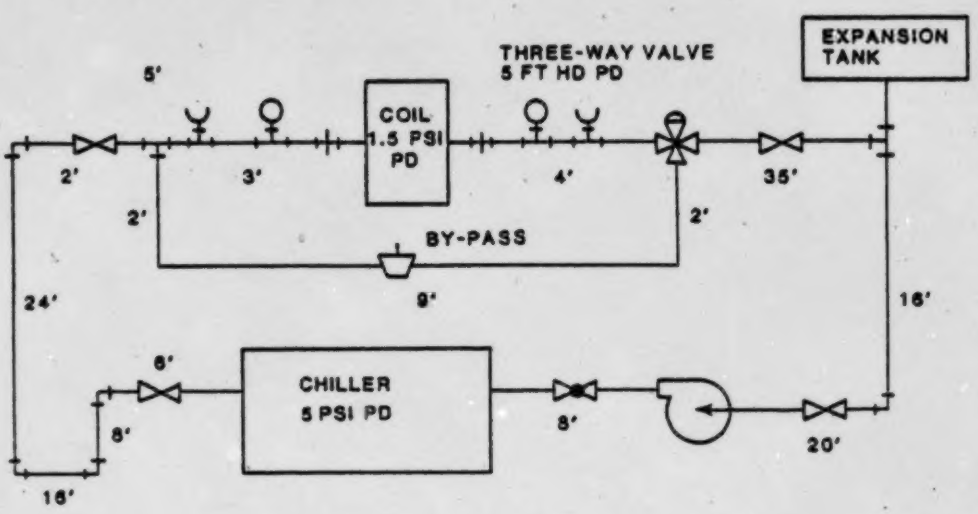


Figure 21. Friction Loss for Open Piping Systems.

EXAMPLE A: CLOSED WATER SYSTEM.

Given: The following dimensions and specifications for a closed water system:


THREE-WAY VALVE
5 FT HD PD
EXPANSION TANK
5'
COIL
1.5 PSI PD
2'
3'
4'
35'
2'
2'
BY-PASS
9'
24'
16'
6'
CHILLER
5 PSI PD
8'
8'
20'
16'

Use schedule 40 steel pipe. Flow rate = 45 gpm (gallons per minute).

Find: Pipe size and pump capacity.

Solution: Pipe size: Refer to Figure 20 for pipe size. A flow rate of 45 gpm gives the following friction losses for standard size pipes:

Pipe Size	Friction loss (ft/100 ft)
1 1/2"	1.4
2"	4.0
2 1/2"	1.7

The 1 1/2" pipe is too small, and the 2 1/2" pipe is larger than necessary. Choose the 2" pipe. This gives a water velocity of 4.3 fps.

Example A. Continued.

Pump capacity: Calculate total equivalent feet of piping system (with bypass valve closed) by adding total length of pipe and equivalent length for all valves and fittings from Tables 4, 5, and 6.

Pipe length = 142.0
Ells, 90°, std = 5 @ 5.0 = 25.0
Tee, str thru = 5 @ 3.3 = 16.5
Tee, branch = 1 @ 10 = 10.0
Gate valve = 4 @ 2.3 = 9.2
Globe valve = 1 @ 55 = 55.0
TOTAL EQUIVALENT FEET 257.7

Calculate head loss for piping and system components. (2.31 ft of water = 1 psi)
Friction loss from chart = 4.0 ft/100 ft

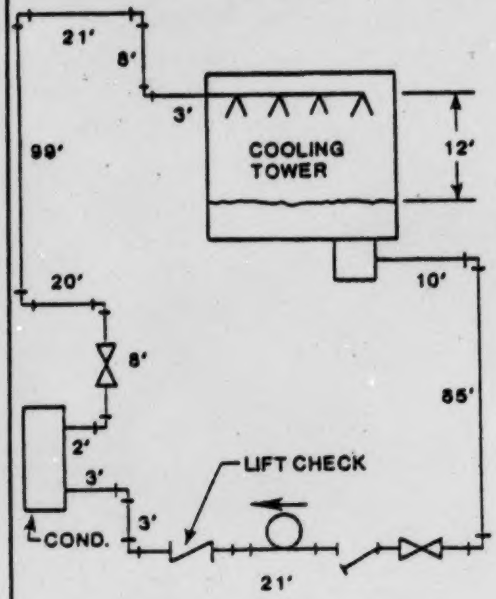
Pipe & ftgs = 257.7 ft x 4 ft/100 ft = 10.31 ft
Chiller = 5 psi x 2.31 ft/psi = 11.55 ft
Coil = 1.5 psi x 2.31 ft/psi = 3.47 ft
3-Way Valve = (given in ft HD) = 5.00 ft
TOTAL PRESSURE DROP = 30.33 ft

A safety factor of 10% is usually added +3.03 ft
Pump pressure = 33.36 ft

Pipe size = 2"
Water velocity = 4.3 fps
Friction loss = 4.0 ft/100 ft
Pump capacity = 33.36 ft of head
45 gpm

EXAMPLE B: OPEN WATER SYSTEM.

Given: The following dimensions and specifications for an open water system:



- Schedule 40 pipe.
- Ells are long radius.
- Flow rate = 1200 gpm.
- Tower nozzles – 8 psi pd.
- Condenser – 13 psi pd.
- Strainer – 4 psi pd.
- Sump exit loss – 24 eq. ft.
- Limit velocity to 8 fps.
- Use 5% safety factor for pump head.

Find: Pipe size and pump capacity.

Solution: Use Figure 21 to determine pipe size. Choose 8" pipe for a velocity of 7.7 fps and a friction loss of 3.8 ft/100 ft.

Determine total equivalent feet of pipe:

Pipe length = 283 ft
Ells, 90°, long rad = 10 @ 13 = 130 ft
Valves, gate = 2 @ 9 = 18 ft
Valve, lift check = 1 @ 220 = 220 ft
Sump exit loss = 24 ft
TOTAL EQUIVALENT FEET 675 ft

Example B. Continued.

Determine total pressure drop:

Pipe & ftgs = 675' x 3.8'/100' = 25.7 ft
Condenser = 13 psi x 2.31 ft/psi = 30.0 ft
Nozzles = 8 psi x 2.31 ft/psi = 18.5 ft
Strainer = 4 psi x 2.31 ft/psi = 9.2 ft
Unbalanced head = 12.0 ft
TOTAL PRESSURE DROP 95.4 ft

Add 5% pump safety factor + 4.8 ft
Pump head = 100.2 ft

Pipe size 8"
Water velocity = 7.7 fps
Friction loss = 3.8 ft/100 ft
Pump capacity = 100.2 ft
1200 gpm

REFRIGERANT PIPING

FUNCTIONS OF PIPING

The obvious function of refrigerant piping is to transport refrigerant vapor and liquid through the system. However, the refrigerant piping system must also transport oil that cannot be separated from the refrigerant and provide for proper component operation, while eliminating the possibility of equipment damage.

Oil from the compressor is always mixed with the refrigerant during compressor operation. Oil separators can be used to remove much of the oil, but it is impossible to remove all of the oil. The remaining oil must travel through the entire system with the refrigerant. In the liquid line, this is no problem, since oil dissolves in the liquid refrigerant and is transported with it. In the hot gas line and the suction line, oil remains in a liquid state and must be swept along by vapor. This requires a minimum vapor velocity of 750 feet per minute (fpm) in horizontal pipes, and 1500 fpm in vertical risers. Vapor velocity should not exceed 3000 fpm.

The piping system must also prevent oil in liquid refrigerant from entering the compressor valves in large quantities, as this damages the compressor. Liquid refrigerant must enter the evaporator in liquid form and be free from vapor. This is accomplished through regulating temperature and pressure.

This section discusses the sizing and design of refrigerant piping to accomplish efficient and safe refrigerant flow. This discussion is based on refrigerant R-12 and type L copper pipe with a condensing temperature of 105°F and a suction temperature of 40°F. These are typical values for air conditioning systems using R-12. Values for other refrigerants and conditions may be found in the reference materials.

HOT GAS PIPE

Figure 22 shows the hot gas velocity as a function of refrigeration load for standard sizes of type L copper pipe.

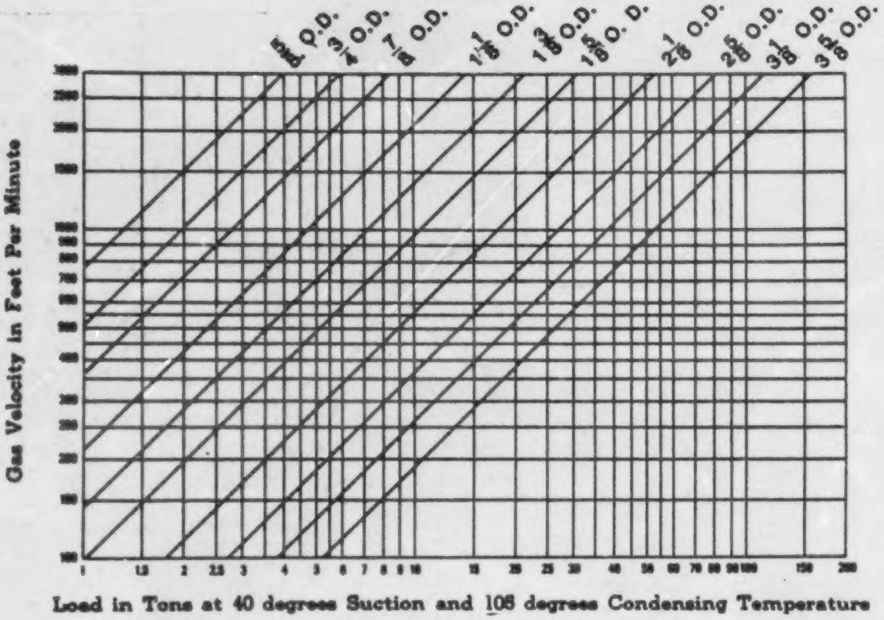


Figure 22. Hot Gas Velocities for Refrigerant 12 Only.

This chart may be used to determine the size of pipe necessary to produce proper gas velocity in the hot gas pipe. The chart illustrates that risers will have a smaller diameter than horizontal runs to produce the required flow rate. It is important that the piping be as large as possible while maintaining proper gas velocities. Total pressure drop in the hot gas pipe should never exceed 3 psi to ensure efficient compressor operation.

If the rise in the hot gas pipe is 8 feet or less, the pipe may rise directly from the compressor to the condenser, as shown in Figure 23. If the rise is more than 8 feet, oil and condensed refrigerant will collect in the pipe when the system is shut down. This liquid can enter the compressor

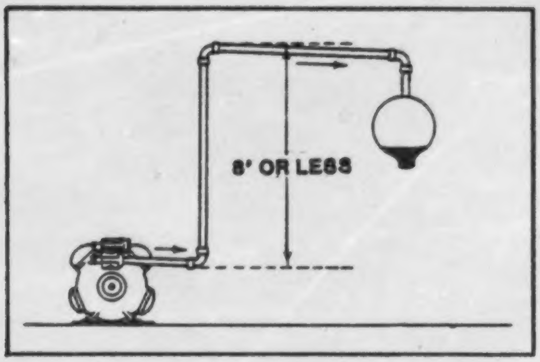


Figure 23.
8 Feet or Less.

discharge valve when the system is restarted and cause damage to the compressor. This is prevented by installing an oil trap as shown in Figure 24. Oil collects in the trap after shut-off and is forced through the system when it is restarted. These figures also illustrate the pitch of refrigerant piping. Horizontal piping runs should be pitched 1/2 inch per 10 feet of run in the direction of refrigerant flow.

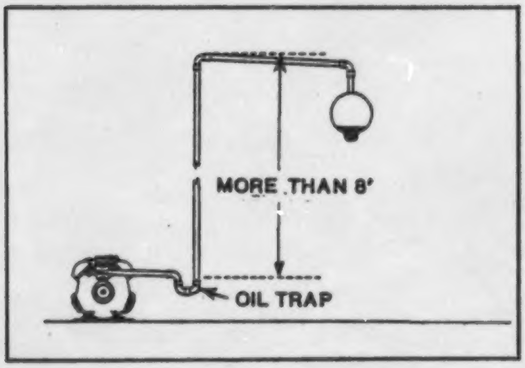
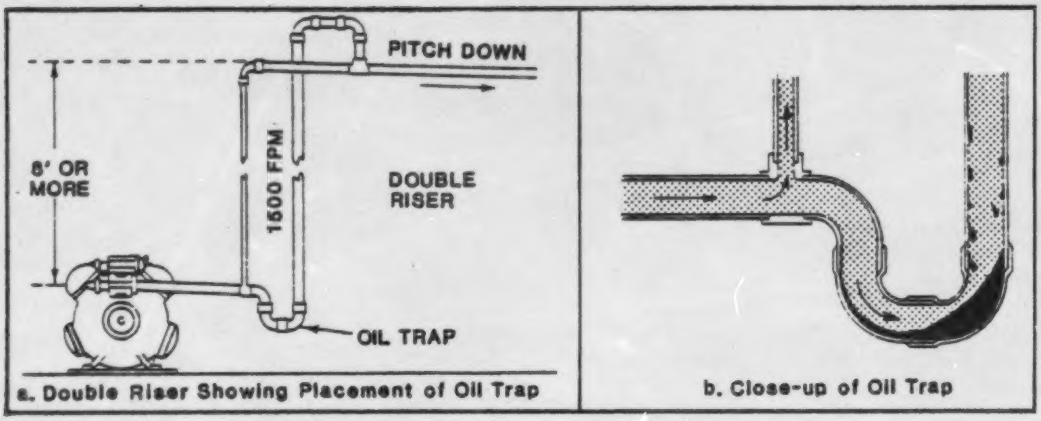


Figure 24.
More Than 8 Feet.

In variable capacity systems, gas velocity is often too low at low capacity to transport oil up the risers. Figure 25 shows a double riser, a technique used to overcome this problem. At full capacity, the oil trap is open and refrigerant vapor flows upward through both pipes. When the



a. Double Riser Showing Placement of Oil Trap

b. Close-up of Oil Trap

Figure 25. Double Riser.

capacity is reduced, oil collects in the trap, blocking flow. All vapor then moves upward through the smaller pipe at a velocity sufficient to move the oil. When the capacity increases again, oil is swept out of the trap.

LIQUID LINE

In the liquid line, oil presents no problems. This pipe can have a relatively small diameter because of the greater density of the liquid. However, another problem arises if the rise of the liquid line is more than a few feet. The pressure in a liquid column depends, in part, upon the density of the liquid and the height of the column. For R-12, each foot of rise results in a pressure drop of 0.55 psi. The temperature of the liquid refrigerant remains the same as height increases. If the pressure drop is too great, some liquid may turn to vapor before it reaches the evaporator. This results in inefficient operation of the expansion valve. Accessories such as strainers and valves add to this problem. The solution is to subcool the liquid refrigerant before it enters the riser. Subcooling of 10°F is sufficient for a rise of 25 ft. The liquid line should be sized to produce a pressure drop, due to friction, of no more than 3 psi.

SUCTION LINE

Figure 26 shows gas velocities for various refrigeration loads and pipe sizes for the suction line. In this pipe, the gas temperature is lower and the density is greater. Thus, the same size pipe results in a lower gas velocity than in the hot gas line. Suction line design is particularly important to system efficiency because compressor efficiency drops

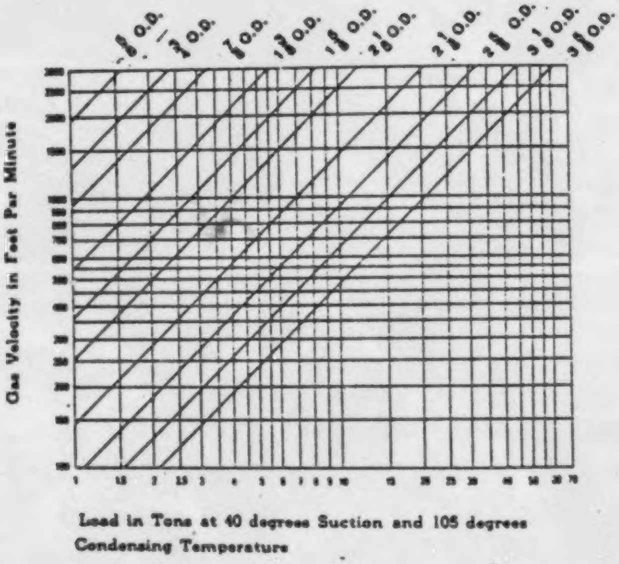


Figure 26. Suction Gas Velocity.

sharply with compressor intake pressure. The total pressure drop in the suction line should not exceed 1 psi. This corresponds to a maximum temperature decrease of 2°F due to gas expansion in the line.

The suction line must be designed to prevent liquid refrigerant from draining from the evaporator to the compressor at shutdown. This is accomplished by placing a trap at the outlet of the evaporator, followed by a riser extending above the top of the evaporator. This trap also holds any oil that is in the evaporator at shutdown. In variable capacity systems, the gas flow rate may be too low at low capacity to transport oil up the riser.

Figure 27 shows one method of overcoming this in small systems. The riser is sized smaller than the remainder of the suction line to provide higher gas velocity at low capacity. At high capacity, gas velocity will be near the 3000 fps limit. Since this riser is short, it does not greatly reduce system efficiency.

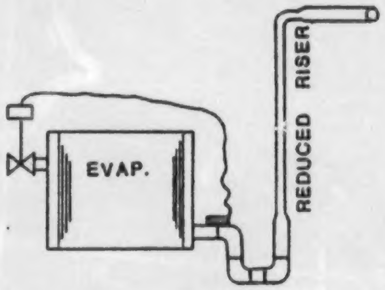


Figure 27. Trap and Short Riser.

In many systems, a double riser and oil trap is used as shown in Figure 28. This figure also shows the connection of two evaporators to one suction line. This arrangement prevents oil or liquid refrigerant in the upper evaporator from entering the lower evaporator.

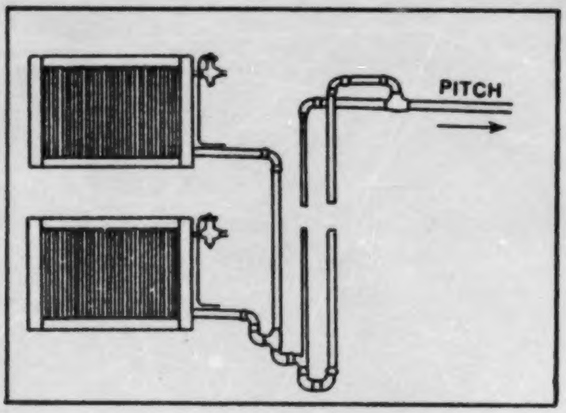


Figure 28. Double Riser and Oil Trap (Two-Evaporator Connection).

MULTIPLE COMPRESSOR CONNECTIONS

Figure 29 shows the suction lines and hot gas lines of two compressors connected in a single system. The suction line is constructed to equalize gas pressure and flow between the two compressors. The suction header is full size,

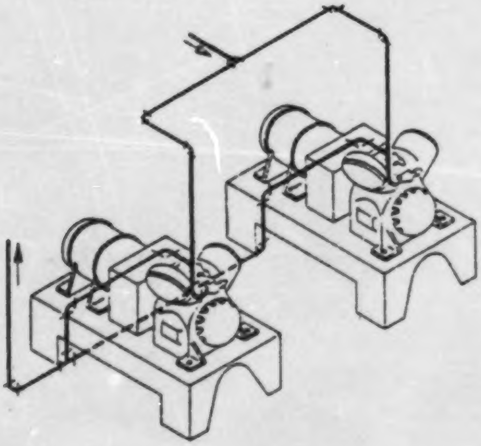


Figure 29. Layout of Suction and Hot Gas Lines for Multiple Compressor Operation.

and is horizontal above the compressors. Branch takeoffs are horizontal from the side of the header and are also full size. No reduction in size is made until the vertical drop. This assures even oil distribution between compressors. Discharge lines are connected to a single header below the discharge level, providing an oil trap.

Figure 30 shows additional piping that is necessary when compressors are paralleled. Oil equalizer lines are connected to compressor cases below oil levels, dropping to

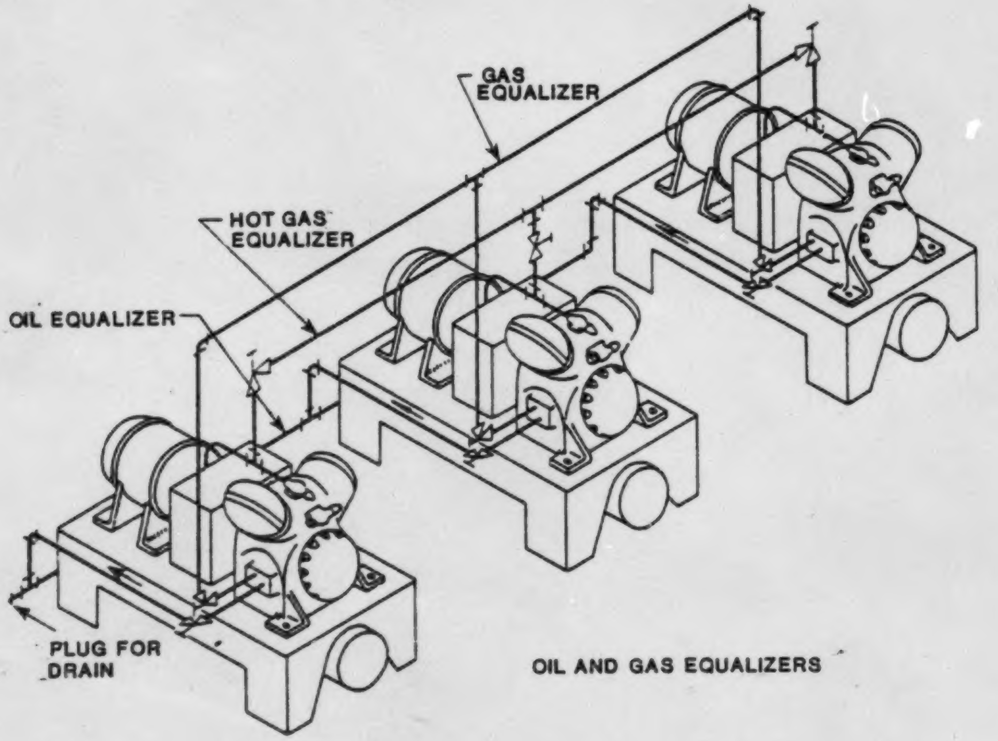

GAS EQUALIZER
HOT GAS EQUALIZER
OIL EQUALIZER
PLUG FOR DRAIN
OIL AND GAS EQUALIZERS

Figure 30. Interconnecting Piping for Multiple Compressors.

a lower level. This allows the oil level to equalize between units. However, this will occur only if the internal pressures in the crank cases are the same. This is assured by gas equalizer lines that are connected to the crank cases above the oil levels and rise to a higher level, preventing oil blockage.

REFRIGERANT PIPE SIZING

Figures 31, 32, and 33 are used to size the suction, hot gas, and liquid lines, respectively. The vertical scale is the equivalent length of the lines and all fittings. The horizontal scale is refrigeration load. Solid lines represent no subcooling, and dashed lines represent subcooling of 15°F. These charts are used along with Figures 22 and 26 to size refrigerant lines. The sizes of pipes are selected using Figures 31, 32, and 33. These sizes are then used in Figures 22 and 26 to determine gas velocities. If the velocities are in the range of 750 fpm to 3000 fpm for horizontal runs and 1500 fpm to 3000 fpm for risers, they are acceptable. If the velocities are not within these ranges, pipe size must be changed. This is illustrated in Example C.

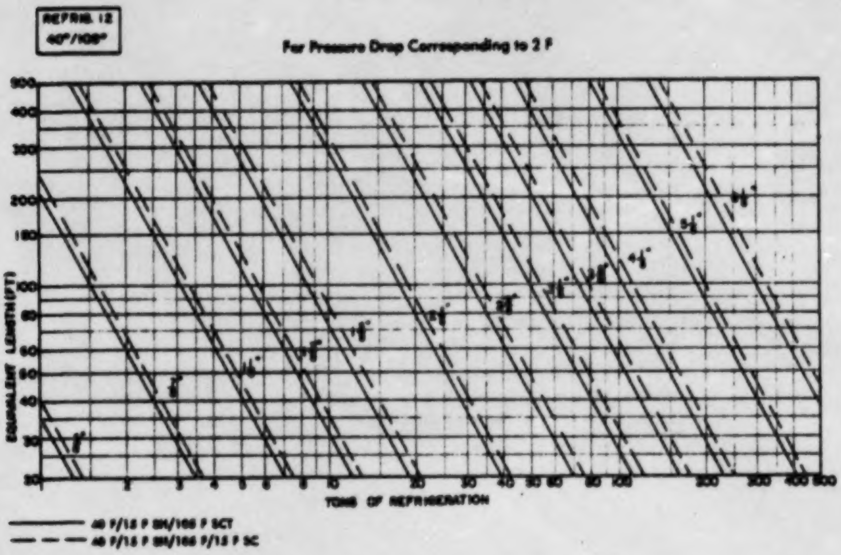


Figure 31. Suction Lines – Copper Tubing.

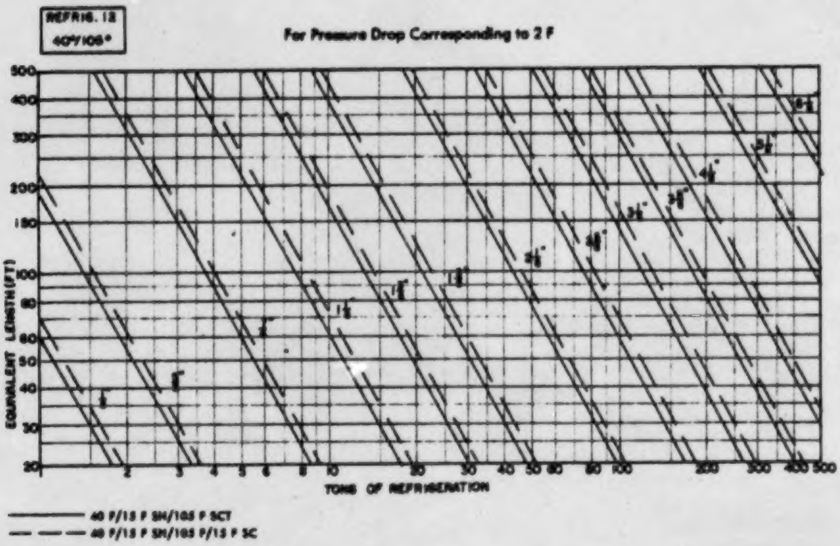
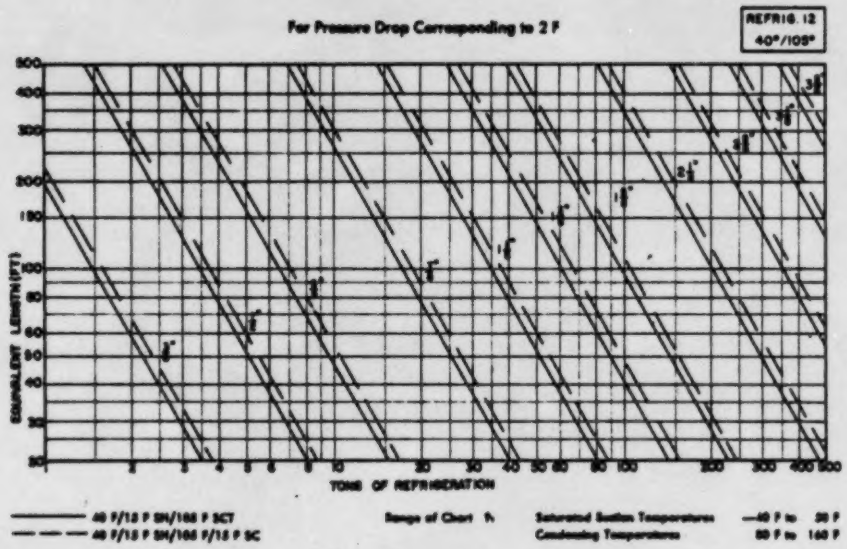


Figure 32. Hot Gas Lines – Copper Tubing.


For Pressure Drop Corresponding to 2 F

Pressure drop is given in equivalent degrees because of the general acceptance of this method of sizing. The corresponding pressure drop in psi may be determined by referring to the saturated refrigerant tables.

To use charts in Figures 31 and 32 for conditions other than 40 F saturated suction, 105 F condensing, multiply the refrigeration load in tons by the factor below and use the product in reading the chart (S = Suction, HG = Hot Gas).

COND TEMP (F)	SATURATED SUCTION TEMPERATURE (F)																			
	−40		−30		−20		−10		0		10		20		30		40		50	
	TONS MULTIPLYING FACTOR																			
	S	HG	S	HG	S	HG	S	HG	S	HG	S	HG	S	HG	S	HG	S	HG	S	HG
80	5.07	1.50	3.92	1.46	3.06	1.43	2.45	1.39	1.96	1.36	1.59	1.33	1.31	1.30	1.08	1.28	0.89	1.25	0.75	1.22
90	—	—	4.11	1.34	3.22	1.31	2.55	1.27	2.05	1.24	1.66	1.21	1.36	1.19	1.12	1.16	0.93	1.14	0.78	1.11
100	—	—	4.33	1.23	3.39	1.20	2.69	1.17	2.15	1.14	1.74	1.11	1.43	1.09	1.18	1.06	0.98	1.04	0.82	1.02
110	—	—	—	—	3.58	1.10	2.83	1.08	2.27	1.05	1.84	1.02	1.50	1.00	1.24	0.98	1.02	0.96	0.85	0.93
120	—	—	—	—	3.80	1.03	3.00	1.00	2.40	0.97	1.94	0.95	1.58	0.93	1.30	0.90	1.08	0.88	0.90	0.86
130	—	—	—	—	—	—	3.19	0.93	2.55	0.91	2.06	0.88	1.68	0.86	1.37	0.84	1.14	0.82	0.95	0.80
140	—	—	—	—	—	—	3.42	0.88	2.73	0.85	2.20	0.83	1.79	0.81	1.46	0.78	1.21	0.76	1.00	0.75
150	—	—	—	—	—	—	—	—	2.29	0.81	2.35	0.78	1.91	0.76	1.56	0.74	1.29	0.72	1.07	0.70
160	—	—	—	—	—	—	—	—	3.17	0.77	2.54	0.74	2.06	0.72	1.69	0.70	1.39	0.68	1.15	0.66

NOTES:

1. To use suction hot gas and liquid line charts for friction drop other than 2 F, multiply equivalent length by factor below and use product in reading chart.

Friction Drop (F)	Liquid Line Hot Gas Line Suction Line	.5	1.0	1.5	2.0	2.5	3.0	4.0	5.0	6.0
Multiplier		4.0	2.0	1.3	1.0	0.8	0.7	0.5	0.4	0.3

2. Pipe sizes are OD and are for Type L copper tubing.

Figure 33. Liquid Lines – Copper Tubing.

EXAMPLE C: REFRIGERANT PIPE SIZING.

Given: A 10-ton air conditioner has piping of the following equivalent lengths:

Suction: 150 ft
Hot gas: 100 ft
Liquid: 50 ft

Find: Pipe sizes required.

Solution:

a. Liquid line from Figure 33: 5/8 inch.

b. Hot gas line from Figure 32: 1 1/8° or 1 3/8". From Figure 22 these give gas velocities of:

1 1/8" – 2100 fpm
1 3/8" – 1400 fpm.

Use 1 1/8" for upward risers and 1 3/8" for horizontal runs and downward risers.

c. Suction line from Figure 31: 1 5/8" or 2 1/8". From Figure 26, these give gas velocities of:

1 5/8" – 2500 fpm
2 1/8" – 1450 fpm

But 2 5/8" give 910 fpm.

Use 1 5/8" for upward risers, and 2 5/8" for horizontal runs and downward risers, to reduce pressure drops.

STEAM PIPING

PIPING CONNECTIONS

Steam pipes must be designed to carry a mixture of steam and liquid water. Even pipes that contain only dry steam during normal operation may contain condensate during startup. Figure 34 illustrates what can happen if steam pipes become blocked by condensate. Steam flowing through the pipe (Figure 34a) produces waves in the water in the pipe that result in the blockage seen in Figure 34b. Steam pressure then forces the water against the riser wall, as seen in Figure 34c. This produces a knocking, known as a water hammer, which may rupture pipes. This situation occurs whenever horizontal runs of steam pipe do not have proper pitch.

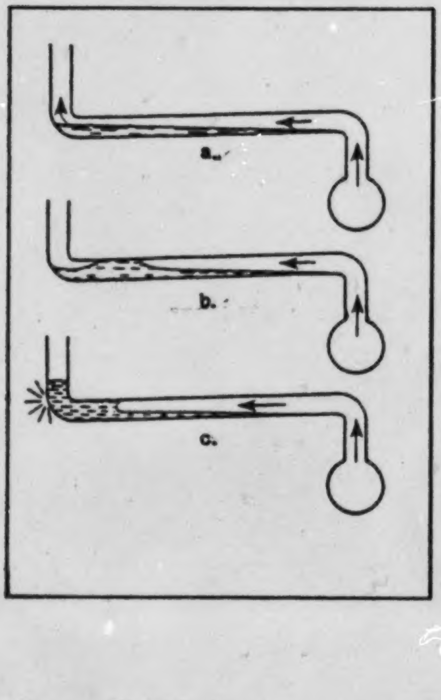


Figure 34. Water Hammer.

Figure 35 illustrates one method of preventing water hammer in steam pipes. The run from the steam main to the riser is pitched at 1/2-inch per foot toward the main. This causes condensate to flow back into the main, instead of collecting in the run. The main is also pitched back toward the boiler, causing liquid to return to the boiler.

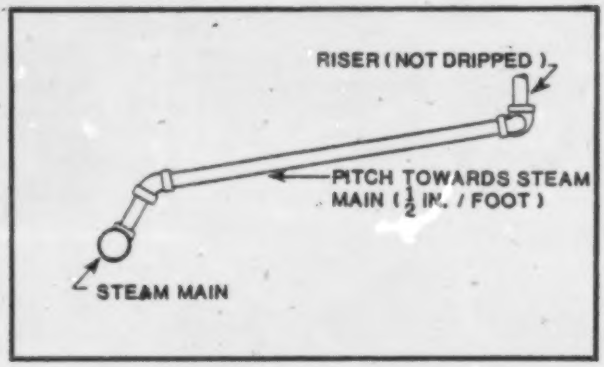

RISER (NOT DRIPPED)
PITCH TOWARDS STEAM MAIN ($\frac{1}{2}$ IN. / FOOT)
STEAM MAIN

Figure 35. Connection to Riser (Not Dripped).

Figure 36 shows a dripped riser. In this case the run is pitched toward the riser. The steam travels up the riser to the point of application, while the condensate flows down the riser to be returned to the boiler. The horizontal main is pitched downward in the direction of flow, so any water in the main also flows down the riser.

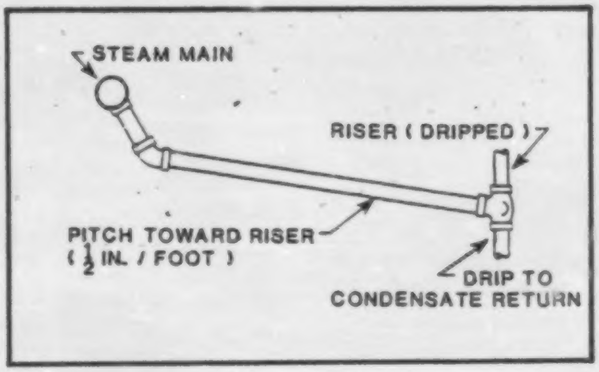

STEAM MAIN
RISER (DRIPPED)
PITCH TOWARD RISER ($\frac{1}{2}$ IN. / FOOT)
DRIP TO CONDENSATE RETURN

Figure 36. Connection to Dripped Riser.

Figure 37 shows how to pipe the steam supply main over vertical obstacles. The large steam main goes over the beam, while the condensate flows through a smaller pipe below the beam. When condensate return lines encounter obstacles, as in Figure 38, the main water pipe goes under the obstacle, and a smaller line for air goes above the obstacle.

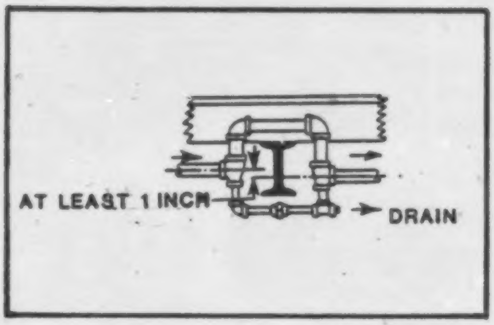


Figure 37. Supply Main Loops.

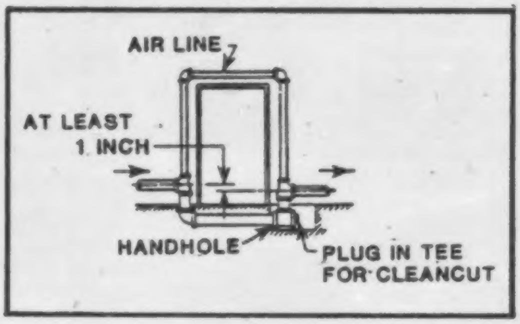
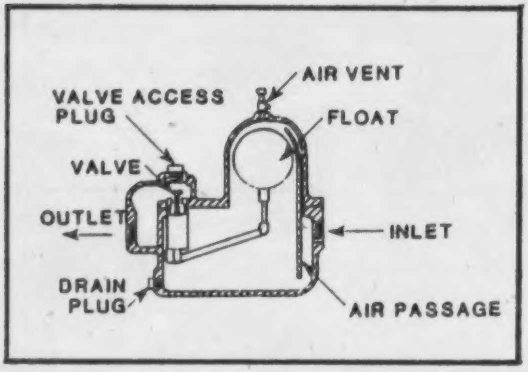


Figure 38. Return Main Loop.

STEAM TRAPS

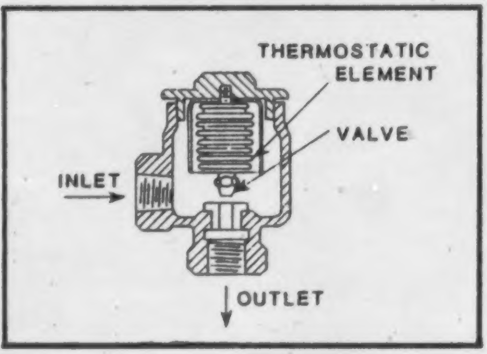
In most steam piping systems, it is necessary to provide traps that allow passage of condensed water, but block the flow of steam. In small systems, this can be accomplished with pipe loops, but special steam traps are usually used. Figure 39 shows a float trap used for this purpose. When the trap fills with water, the float rises, opening the valve and allowing water to flow through the trap. When the trap fills with steam, the float drops, closing the valve. A thermostatic air vent in the trap allows cool air to escape, but closes when heated by escaping steam.

Figure 39. Float Trap.


AIR VENT
VALVE ACCESS PLUG
FLOAT
VALVE
OUTLET
INLET
DRAIN PLUG
AIR PASSAGE

A thermostatic steam trap is shown in Figure 40. This trap contains an element that contracts to open the valve when it is in contact with relatively cool condensate. The element expands to close the valve when it is in contact with steam. Several other types of steam traps are also in common use.

Figure 40. Thermostatic Trap, Bellows Type.


THERMOSTATIC ELEMENT
VALVE
INLET
OUTLET

SYSTEM TYPES

Steam heating systems are classified, according to operating pressure, into the following five system types:

1. High pressure systems operate with steam pressures of 100 psi or more.
2. Medium pressure systems operate at 15 to 100 psi.
3. Low pressure systems have steam pressures of 0 to 15 psi.
4. Vapor systems operate between vacuum and 15 psi.
5. Vacuum systems have the same operating pressure range as vapor systems. They are identical except that vacuum systems have vacuum pumps and vapor systems do not.

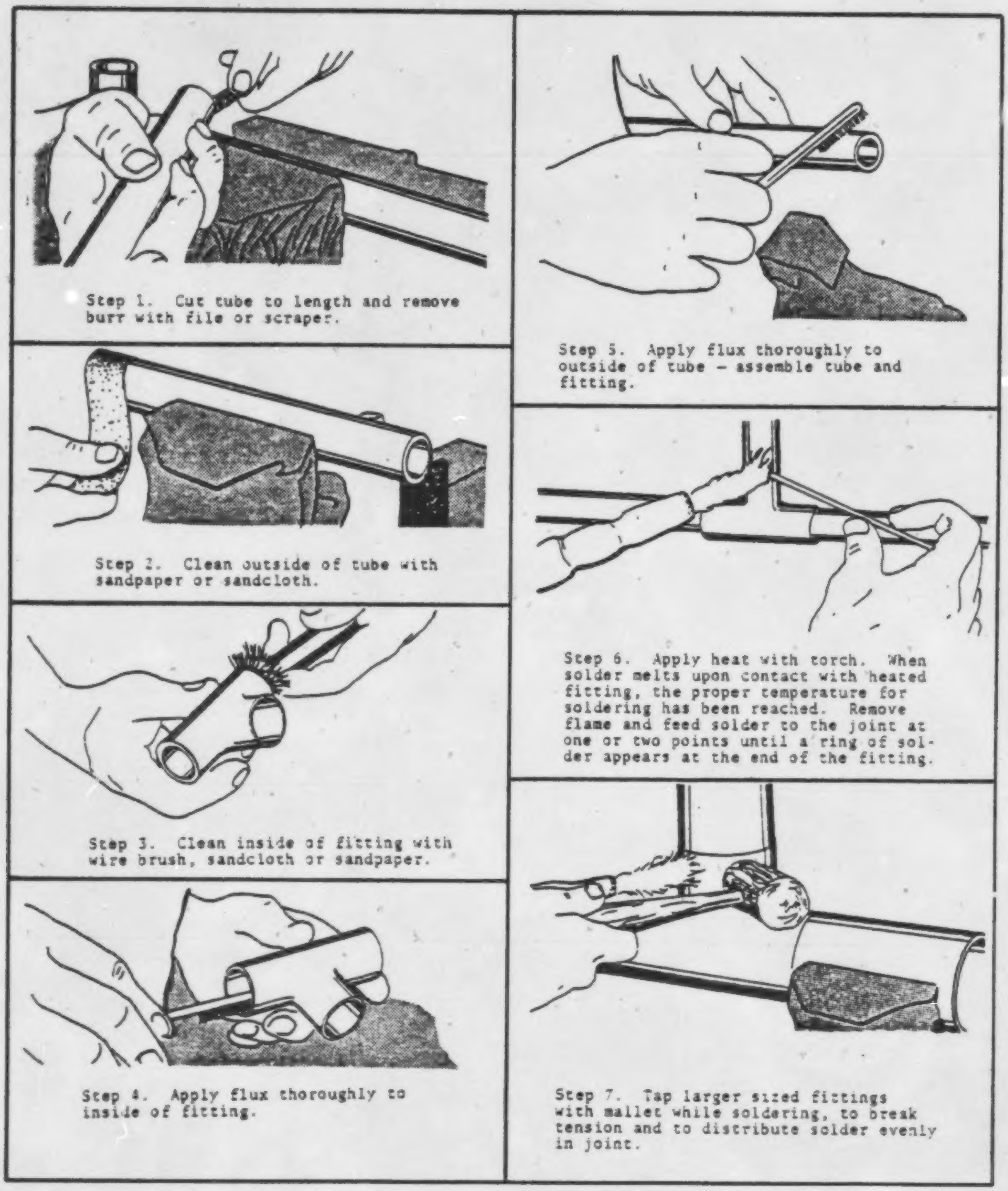
All these systems may be used in heating applications. Most small systems are low pressure systems. Larger systems may be of any type; however, low pressure systems are the most common.

SOLDERING AND BRAZING COPPER TUBING

SOLDERING

Soldering requires temperatures of less than 1000°F. Soldering is usually accomplished at about 500°F in air conditioning work. Figure 41 illustrates the proper steps in soldering.

Successful soldering depends upon careful cleaning of the surfaces to be soldered. Surfaces may be cleaned with sandpaper, steel wool, or a wire brush. Emery cloth should not be used, since particles of abrasive left in the pipe can cause damage to mechanical components. Flame should not be applied directly to the surfaces to be joined, since this



Step 1. Cut tube to length and remove burr with file or scraper.

Step 2. Clean outside of tube with sandpaper or sandcloth.

Step 3. Clean inside of fitting with wire brush, sandcloth or sandpaper.

Step 4. Apply flux thoroughly to inside of fitting.

Step 5. Apply flux thoroughly to outside of tube - assemble tube and fitting.

Step 6. Apply heat with torch. When solder melts upon contact with heated fitting, the proper temperature for soldering has been reached. Remove flame and feed solder to the joint at one or two points until a ring of solder appears at the end of the fitting.

Step 7. Tap larger sized fittings with mallet while soldering, to break tension and to distribute solder evenly in joint.

Figure 41. Recommended Procedures to Follow When Soldering Tubing.

will produce oxidation that will prevent a good solder joint. The work piece should be heated to the proper temperature, and the flame should be removed while the solder is applied. Overheating will result in poor seals. Large pipes are tapped with a hammer to aid solder flow into the joint.

BRAZING

Brazing is similar to soldering, but requires temperatures of over 1000°F. Figures 42 and 43 illustrate the proper methods of heating parts to be brazed and applying the brazing alloy. The proper temperature has been reached when the flux turns from a milky appearance to clear. Brazed joints should be cleaned thoroughly to remove the flux. This prevents corrosion.

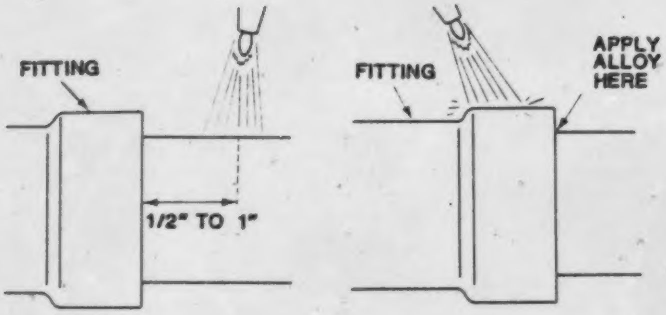


Figure 42. Brazing Horizontal Joints.

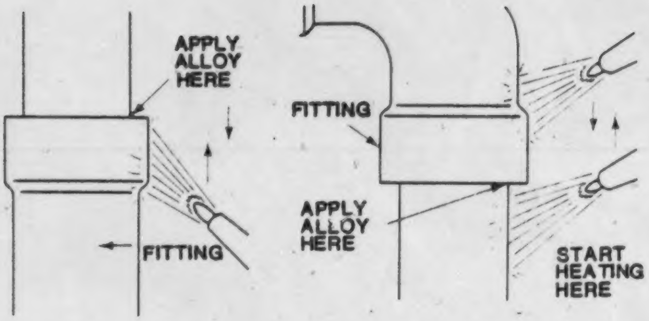

APPLY ALLOY HERE
FITTING
FITTING
APPLY ALLOY HERE
START HEATING HERE

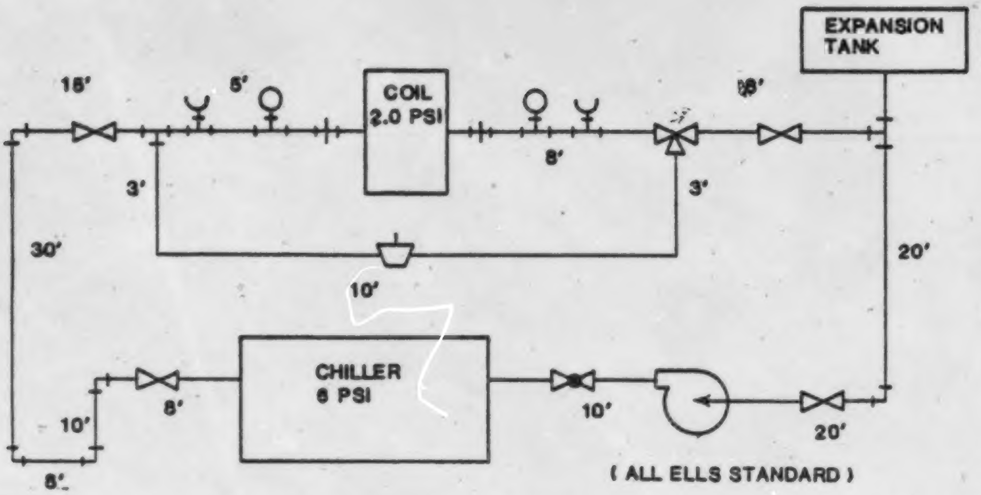
Figure 43. Brazing Vertical Joints.

SUMMARY

Piping is an essential part of air conditioning and heating systems. All pipes should be sized properly and laid out in a manner that provides efficient fluid flow without introducing problems. Sizing of refrigerant hot gas and suction lines is most critical to proper system operation. Incorrect pipe size or improper layout in refrigeration systems can greatly reduce system capacity and efficiency.

EXERCISES

1. Explain the difference in function and fluid resistance of various valve types.
2. Explain the applications of the three types of water piping systems.
3. Explain the problems likely to be encountered if the following mistakes are made in piping:
    a. Water pipes too small.
    b. Globe valve replaced with gate valve.
    c. Gate valve replaced with angle valve.
    d. Refrigerant suction line too small.
    e. Refrigerant hot gas line too large.
    f. Refrigerant liquid line rise of 30 feet with 5°F subcooling.
    g. Horizontal run to non-dripped steam riser pitched in the wrong direction.
    h. Oil trap omitted from hot gas line with a rise of 15 feet.
    i. Upward riser omitted from suction line at evaporator.
    j. Water piping system unbalanced.
    k. Water strainer installed in expansion line.
    l. Oil equalization lines run above compressor oil levels.
    m. Hot gas equalization line with tees in vertical rise.
4. The following water piping system has a flow rate of 2000 gpm. Determine pipe size and pump capacity.


15'
5'
COIL
2.0 PSI
8'
18'
EXPANSION
TANK
3'
3'
30'
20'
10'
CHILLER
6 PSI
8'
10'
10'
20'
8'

(ALL ELLS STANDARD)

5. A 20-ton refrigeration system has equivalent pipe lengths of:

Suction line = 150 feet.
Hot gas line = 180 feet.
Liquid line = 62 feet.

Determine the pipe sizes required.

LABORATORY MATERIALS

Copper tubing of several sizes.
Connectors for tubing.
Soft solder and flux.
Silver solder and flux.
Oxyacetylene torch.
Safety goggles.
Sandpaper.

Wire brush.
File.
Tubing cutter.
Hammer.
Vice.
Hacksaw.
Flame ignitor.

LABORATORY PROCEDURES

LABORATORY 1. SAFETY PRECAUTIONS.

The laboratory instructor will demonstrate all equipment and procedures. Take notes on all procedures. List all safety precautions in Data Table 1.

LABORATORY 2. SOLDERING AND BRAZING.

1. Using all safety precautions and the demonstrated procedures, construct the soldered and brazed joints assigned.
2. Using the vice and hacksaw, cut the joints in half and observe the joint. Describe any problems or faults in Data Table 2.
3. The instructor should check student work and evaluation.

DATA TABLES

DATA TABLE 1. SAFETY PRECAUTIONS.

SAFETY PRECAUTIONS:

DATA TABLE 2. SOLDERING AND BRAZING.

EVALUATION OF SOLDER JOINTS First attempt: Second attempt:
EVALUATION OF BRAZED JOINTS First attempt: Second attempt:

REFERENCES

Althouse, Andrew D.; Turnquist, Carl H.; and Bracciano, Alfred F. Modern Refrigeration and Air Conditioning. Homewood, IL: The Goodheart Willcox Co., Inc., 1979.

Air Conditioning and Refrigeration Institute. Refrigeration and Air Conditioning. Englewood Cliffs, NJ: Prentice-Hall, Inc., 1979.

Carrier Air Conditioning Co. Carrier Systems Design Manual, Part 3: Piping Design. Syracuse, NY: Carrier Corp., 1973.

TEST

1. A water system with reverse return headers and direct return risers...
   a. requires balancing valves unless all units are identical.
   b. is commonly used to serve several cooling towers.
   c. is an open water system.
   d. is often used with fan coils of different sizes.
   e. None of the above.
2. If a gate valve in a water line is replaced with a Y valve...
   a. the maximum flow rate of the system will decrease.
   b. the flow rate may be more easily controlled.
   c. the pressure drop across the valve will increase.
   d. All of the above.
   e. Only a and b are true.
3. The oil trap may be eliminated from the hot gas line if...
   a. an oil separator is used.
   b. the rise of the hot gas line is less than 8 feet.
   c. the diameter of the hot gas line is reduced to provide greater gas velocity.
   d. Either a or b.
   e. None of the above.
4. If the suction line is too small, system efficiency drops due to...
   a. too much oil being sucked into the compressor.
   b. too much pressure loss in the suction line.
   c. oil collecting in the evaporator.
   d. All of the above.
   e. None of the above.

5. Steam mains in low and medium pressure systems...
   a. are pitched toward non-dripped risers.
   b. are pitched away from dripped risers.
   c. need not be pitched, since they carry no condensate during normal operation.
   d. Both a and b are true.
   e. None of the above.
6. The greatest resistance to flow in any fluid system is produced by...
   a. elbows.
   b. gate valves.
   c. globe valves.
   d. angle valves.
   e. Y valves.
7. Oil traps are commonly located...
   a. in the hot gas line near the compressor.
   b. in the suction line near the evaporator.
   c. in the suction line near the compressor.
   d. in the hot gas line near the condenser.
   e. Both a and b.
8. Variable capacity air conditioning systems will probably have...
   a. double risers in the hot gas line.
   b. double risers in the suction line.
   c. gas velocities of near 3000 fpm in all risers at full capacity.
   d. gas velocities of less than 1500 fpm in all risers at minimum load.
   e. All of the above.
   f. None of the above.
   g. Only a and c.

h. Only b and c.
i. Only a, b, and c are true.
j. Only a, b, and d are true.

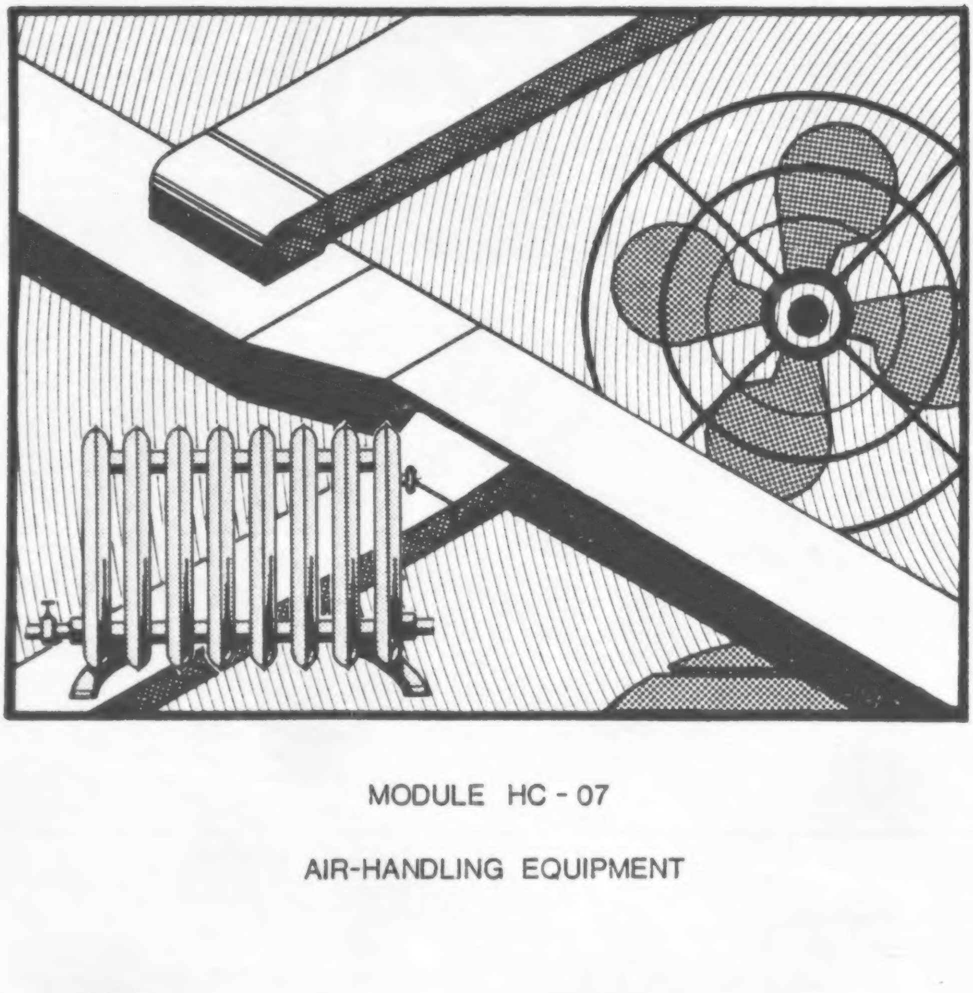
9. The most likely place to find a list check valve is the...
    a. riser of a direct return water system.
    b. horizontal run of a direct return water system.
    c. steam riser.
    d. liquid refrigerant line.
    e. Both a and b.

10. The largest diameter pipe in a refrigeration system is the...
    a. liquid line.
    b. hot gas line.
    c. suction line.
    d. risers in the suction line.

ENERGY TECHNOLOGY

CONSERVATION AND USE

HEATING, VENTILATING, AND AIR CONDITIONING



MODULE HC - 07

AIR-HANDLING EQUIPMENT

CORD CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

INTRODUCTION

Both comfort provided and operating efficiency of any air-conditioning or heating system depend heavily upon the air handling equipment used to deliver conditioned air to space served. Proper design and installation of ductwork is particularly important, since this is usually an integral part of constructing the building, and cannot be changed once installed. This module describes fans and ducts used to handle air, methods of introducing conditioned air into space, and the basic duct layouts of several systems. In the laboratory, the student will visit a large HVAC installation and examine air-handling equipment.

PREREQUISITES

The student should have completed Module HC-02, "System Types"; HC-03 "Refrigeration Equipment"; and HC-05, "Boilers for Heating Applications."

OBJECTIVES

Upon completion of this module the student should be able to:

1. Define static pressure, velocity pressure, and total pressure, and draw a diagram showing how they vary along a duct of varying size.
2. Given any two of the following quantities for an air duct and the charts in the subject matter, determine the other two quantities:

   a. Size or dimensions.
   b. Air velocity.
   c. Volume flow rate.
   d. Friction loss.
3. Given diagrams of various types of fittings and duct takeoffs, identify those that have high resistance and those that have low resistance.
4. Describe the three methods of duct design.
5. Describe the air flow patterns of four groups of air outlets for both heating and cooling service.
6. List the characteristics and applications of the following fan types:
   a. Radial blade fan.
   b. Forward curved fan.
   c. Backward curved fan.
   d. Vaneaxial fan.
7. Explain the advantages and disadvantages of airfoil blades.
8. List the total pressures of the four fan classes.
9. Draw diagrams of the main supply ducts and branch ducts of the following air conditioning systems:
   a. Single zone constant volume.
   b. Single zone variable volume.
   c. Multizone constant volume.
   d. Dual duct.
10. Take a field trip to a large HVAC installation and examine the air-handling equipment.
11. Use all data and sketches of the system to prepare a detailed description of the entire system.

SUBJECT MATTER

BASIC AIR FLOW PRINCIPLES

Figure 1 shows basic components of the air-handling system of an air conditioning or heating system. Air is forced through a duct network by a centrifugal blower. Energy supplied by the blower must deliver the necessary volume of air to the conditioned space and overcome all system losses. Important loss factors are indicated in the figure.

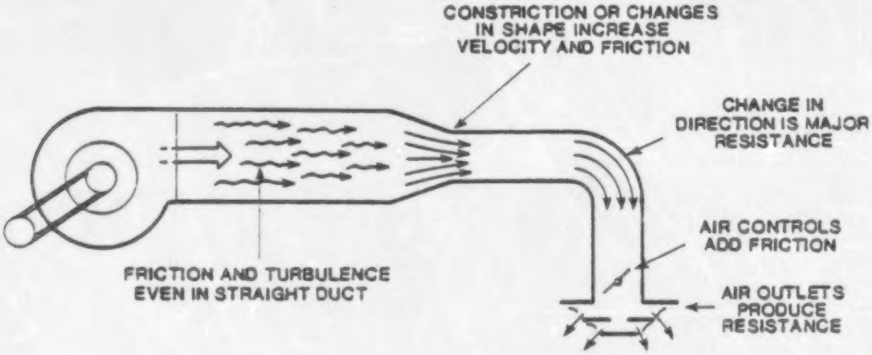

CONSTRICTION OR CHANGES IN SHAPE INCREASE VELOCITY AND FRICTION
CHANGE IN DIRECTION IS MAJOR RESISTANCE
AIR CONTROLS ADD FRICTION
AIR OUTLETS PRODUCE RESISTANCE
FRICTION AND TURBULENCE EVEN IN STRAIGHT DUCT

Figure 1. Duct System.

Air pressure in the duct is comprised of two components. Static pressure is the pressure exerted against duct walls in all directions. It is usually positive (with respect to atmospheric pressure) in supply ducts, and negative in return ducts. Velocity pressure is pressure in the direction of flow produced by the motion of air. Total pressure is the sum of static pressure and velocity pressure.

Figure 2 shows the relationships of these three pressures in a duct system. Total pressure in the system always

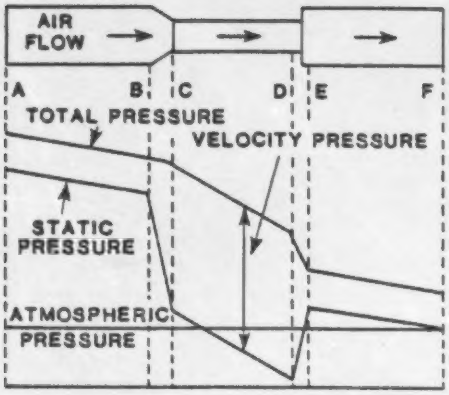


Figure 2. Pressure Changes During Flow in Ducts.

decreases in the direction of air flow, but individual components may either increase or decrease. Between points A and B, air flows through a straight duct (of constant size) at a constant velocity. Velocity pressure remains constant, but both static pressure and total pressure drop, due to frictional losses.

In converging section BC, the duct area is reduced and velocity increases. This converts static pressure to velocity pressure, but does not greatly reduce total pressure. In section CD, air velocity and velocity pressure are constant. Since friction loss is nearly proportional to velocity, total and static pressures drop more rapidly than in section AB.

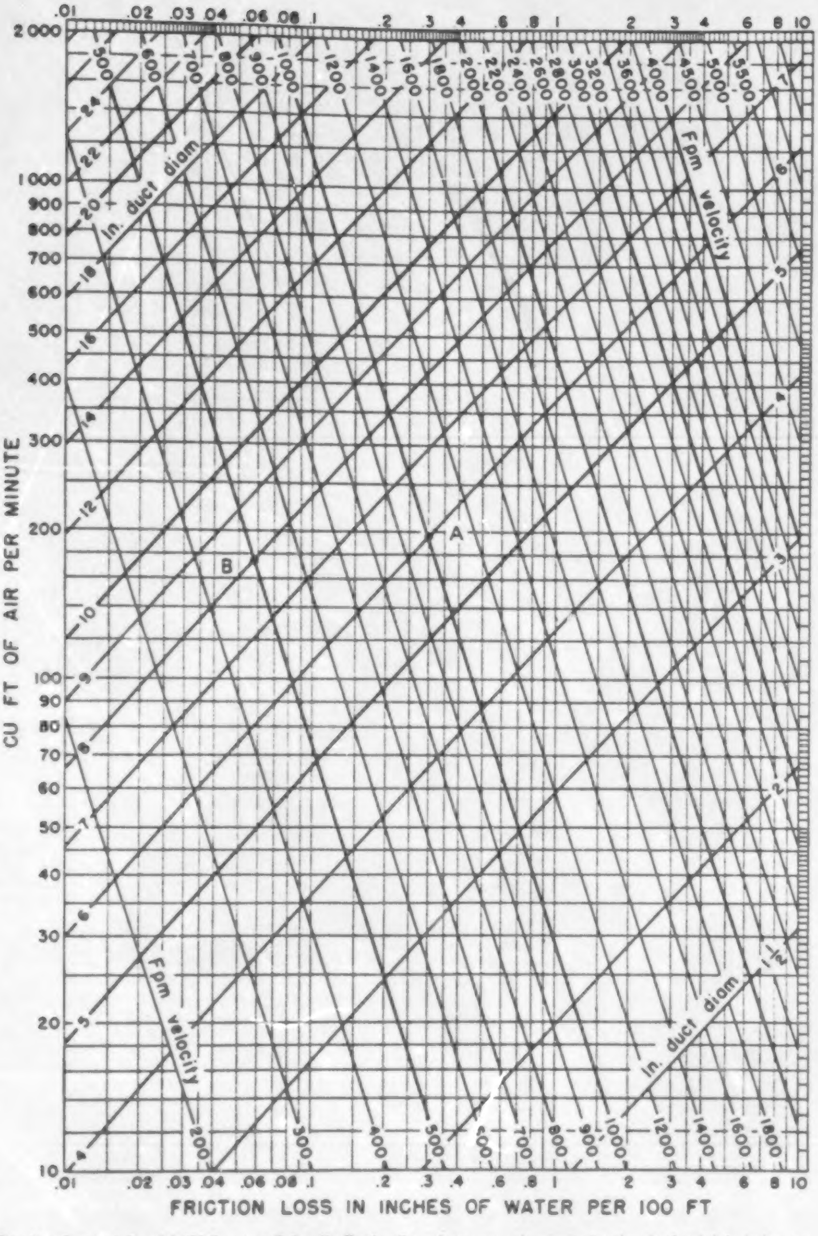
An abrupt expansion occurs in section DE. Air slows and velocity pressure drops, resulting in increased static pressure. Turbulence produced by the abrupt expansion causes a large loss in total pressure. At point F, air is discharged into the conditioned space (at atmospheric pressure) with sufficient velocity pressure to move the air into the conditioned space. It is important to note that total pressure always decreases, but the ratio of static pressure to velocity pressure is dependent upon air velocity.

FRICTION LOSSES IN DUCTS

AIR FRICTION CHARTS

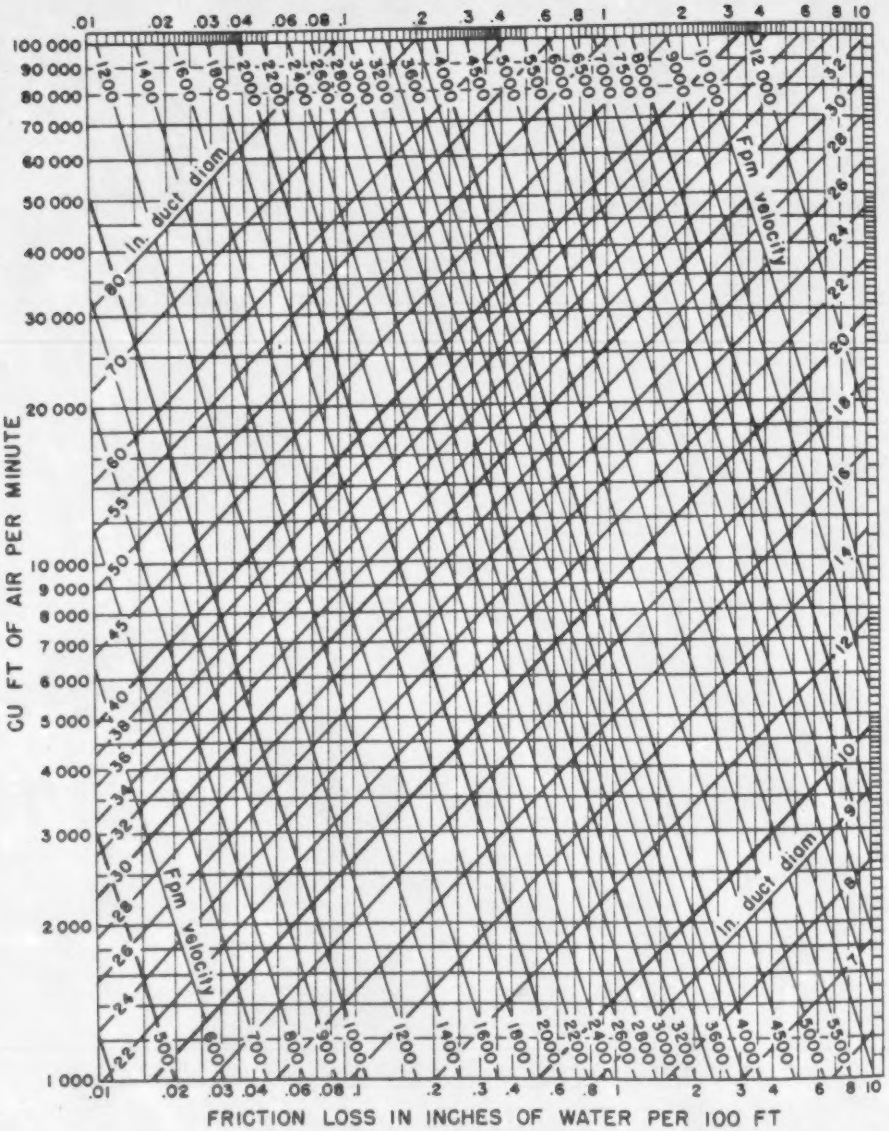
Duct air pressures are measured in terms of inches of water column. Resistance to air flow through a duct is described in terms of the total pressure drop per 100 feet necessary to move air through the duct at a specified velocity. Figure 3 is a chart relating flow rate, pressure drop, duct diameter, and volume of air moved. If any two of these quantities are know, the other two may be determined from the chart. For example, point A represents a 6"-diameter duct delivering 200 ft^3/min. The velocity in this duct must be 1000 fpm, and the friction loss is 0.3" of water per 100 feet of duct. If this duct is 75 feet long, its total pressure drop would be 0.75 x 0.3 = 0.225" of water. Point B represents an 8" duct with an air velocity of 500 fpm. It delivers air at 175 ft^3/min and has a friction loss of 0.058" of water per 100 feet.

Figure 4 is a similar chart for higher velocities and larger ducts. These two charts are for round ducts. If rectangular ducts are used, the equivalent diameter of a circular duct may be determined using Table 1. The large numbers overprinted on this table are called duct class numbers. A higher number indicates a higher initial cost of the ductwork.



(Based on Standard Air of 0.075 lb per cu ft density flowing through average, clean, round, galvanized metal ducts having approximately 40 joints per 100 ft.) Caution: Do not extrapolate below chart.

Figure 3. Friction of Air in Straight Ducts for Volumes of 10 to 2000 cfm.



(Based on Standard Air of 0.075 lb per cu ft density flowing through average, clean, round, galvanized metal ducts having approximately 40 joints per 100 ft.)

Figure 4. Friction of Air in Straight Ducts for Volumes of 1000 to 100,000 cfm.

TABLE 1.

DUCT DIMENSIONS, SECTION AREA,/CIRCULAR EQUIVALENT DIAMETER, AND DUCT CLASS.

SIDE	6		8		10		12		14		16		18		20		22	
	Area sq ft	Diam in.	Area sq ft	Diam in.	Area sq ft	Diam in.	Area sq ft	Diam in.	Area sq ft	Diam in.	Area sq ft	Diam in.	Area sq ft	Diam in.	Area sq ft	Diam in.	Area sq ft	Diam in.
10	.39	8.4	.52	9.8	.65	10.9												
12	.45	9.1	.62	**1** [illegible].7	.77	11.9	94	13.1										
14	.52	9.8	.72	[illegible].5	.91	12.9	1.09	14.2	1.28	15.3								
16	.59	10.4	.81	12.2	1.02	13.7	1.24	[illegible]	1.45	16.3	1.67	17.5						
18	.66	11.0	.91	12.9	1.15	14.5	1.40	**2**	1.63	17.3	1.87	18.5	2.12	19.7				
20	.72	11.5	.99	13.5	1.26	15.2	1.54	[illegible]	1.81	18.2	2.07	19.5	2.34	20.7	2.61	21.9		
22	.78	12.0	1.08	14.1	1.38	15.9	1.69	17.6	1.99	19.1	2.27	20.4	2.57	21.7	2.86	22.9	3.17	24.1
24	.84	12.4	1.16	14.6	1.50	16.6	1.83	18.3	2.14	19.8	2.47	21.3	2.78	22.6	3.11	23.9	3.43	25.1
26	.89	12.8	1.26	15.2	1.61	17.2	1.97	19.0	2.31	20.6	2.66	22.1	3.01	23.5	3.35	24.8	3.71	26.1
28	.95	13.2	1.33	15.6	1.71	[illegible].7	2.09	19.6	2.47	21.3	2.86	22.9	3.25	24.4	3.60	25.7	4.00	27.1
30	1.01	13.6	1.41	16.1	1.82	**3** [illegible].3	2.22	20.2	2.64	22.0	3.06	23.7	3.46	25.2	3.89	26.7	4.27	28.0
32	1.07	14.0	1.48	16.5	1.9[illegible]	18.8	2.36	20.8	2.81	22.7	3.25	24.4	3.68	26.0	4.12	27.5	4.55	28.9
34	1.13	14.4	1.58	17.0	2.03	19.3	2.49	21.4	2.96	23.3	3.43	25.1	3.89	26.7	4.37	28.3	4.81	29.7
36	1.18	14.7	1.65	17.4	2.14	19.8	2.61	21.9	3.11	23.9	3.63	25.8	4.09	27.4	4.58	29.0	5.07	30.5
38	1.23	15.0	1.73	17.8	2.25	20.3	2.76	22.5	3.27	24.5	3.80	26.4	4.30	28.1	4.84	29.8	5.37	31.4
40	1.28	15.3	1.81	18.2	2.33	20.7	2.88	23.0	3.43	25.1	3.97	27.0	4.52	28.8	5.07	30.5	5.62	32.1
42	1.33	15.6	1.86	18.5	2.43	21.1	2.98	23.4	3.57	25.6	4.15	27.6	4.71	29.4	5.31	31.2	5.86	32.8
44	1.38	15.9	1.95	18.9	2.52	21.5	3.11	23.9	3.71	26.1	4.33	28.2	4.90	30.0	5.55	31.9	6.12	33.5
46	1.43	16.2	2.01	19.2	2.61	21.9	3.22	24.3	3.88	26.7	4.49	28.7	5.10	30.6	5.76	32.5	6.37	34.2
48	1.48	16.5	2.09	19.6	2.71	22.3	3.35	24.8	4.03	27.2	4.63	29.2	5.30	31.2	5.97	33.1	6.64	34.9
50			2.16	19.9	2.81	22.7	3.46	25.2	4.15	27.6	4.[illegible] **4**	29.8	5.51	31.8	6.19	33.7	6.87	35.5
52			2.22	20.2	2.91	23.1	3.57	25.6	4.30	28.1	5.00	[illegible]0.3	5.72	32.4	6.41	34.3	7.14	36.0
54			2.29	20.5	2.98	23.4	3.71	26.1	4.43	28.5	5.17	30.8	5.90	32.9	6.64	34.9	7.38	36.8
56			2.38	20.9	3.09	23.8	3.83	26.5	4.55	28.9	5.31	31.2	6.08	33.4	6.87	35.5	7.62	37.4
58			2.43	21.1	3.19	24.2	3.94	26.9	4.68	29.3	5.48	31.7	6.26	33.9	7.06	36.0	7.87	38.0
60			2.50	21.4	3.27	24.5	4.06	27.3	4.84	29.8	5.65	32.2	6.50	34.5	7.26	36.5	8.12	38.6
64			2.64	22.0	3.46	25.2	4.24	27.9	5.10	30.6	5.91	33.1	6.87	35.5	7.71	37.6	8.59	39.7
68					3.63	25.8	4.49	28.7	5.37	31.4	6.26	33.9	7.18	36.3	8.12	38.6	9.03	40.7
72					3.83	26.5	4.71	29.4	5.69	32.3	6.60	34.8	7.54	37.2	8.50	39.5	9.52	41.8
76					4.09	27.4	4.91	30.0	5.86	32.8	6.83	35.4	7.95	38.2	8.90	40.4	9.98	42.8
80					4.15	27.6	5.17	30.8	6.15	33.6	7.22	36.4	8.29	39.0	9.21	[illegible]	10.4	43.8
84							5.41	31.5	6.41	34.5	7.54	37.2	8.55	39.6	9.75	**5**	10.8	44.6
88							5.58	32.0	6.64	34.9	7.87	38.0	8.94	40.5	10.1	[illegible]	11.2	45.4
92							5.79	32.6	6.91	35.6	8.12	38.6	9.39	41.5	10.4	43.8	11.7	46.3
96							5.90	33.0	7.14	36.2	8.40	39.2	9.70	42.1	10.8	44.5	12.1	47.2
100									7.40	36.9	8.50	39.5	9.80	42.5	11.3	45.5	12.3	47.6
104									7.60	37.4	8.90	40.5	10.3	43.5	11.6	46.2	13.0	48.8
108									7.90	38.0	9.20	41.2	10.6	44.0	12.0	47.0	13.4	49.6
112									8.10	38.6	9.50	41.8	10.9	[illegible].7	12.3	47.5	13.8	50.3
116											9.80	42.4	11.3	**6** [illegible].5	12.6	48.1	14.3	51.3
120											10.0	42.8	11.5	[illegible]6.0	13.1	49.1	14.4	51.5
124											10.3	43.5	11.9	46.7	13.4	49.6	15.0	52.4
128											10.6	44.1	12.1	47.1	13.8	50.4	15.5	53.3
132													12.5	47.9	14.1	50.9	15.8	53.9
136													12.8	48.5	14.5	51.6	16.2	54.5
140													13.0	48.8	14.7	52.0	16.5	55.0
144													13.3	49.4	15.2	52.9	16.8	55.6

DUCT FITTINGS

A wide variety of fittings are available for changing the direction of ducts and for branching. Figure 5 illustrates angles and elbows for rectangular ducts. The resistance of each fitting is specified in terms of the length of a straight duct of the same size with equal resistance to air flow. Greater bends and sharper angles have higher resistances. Square corners (style D) include internal turning vanes to reduce resistance.

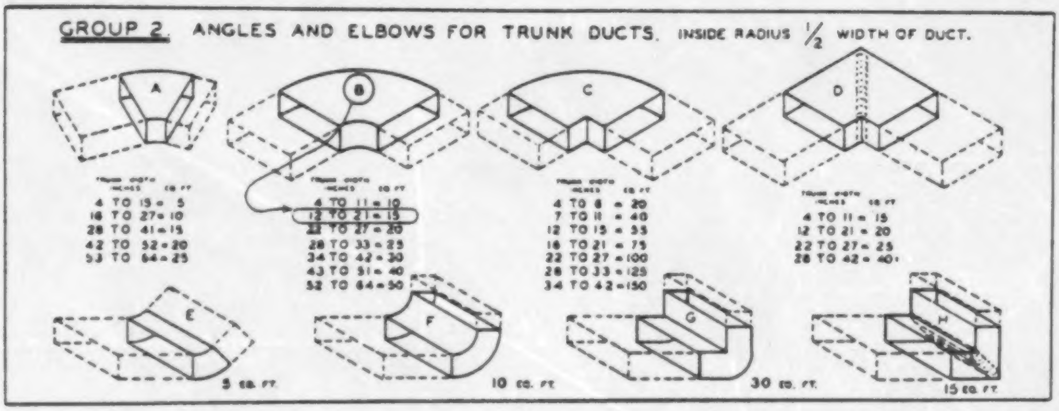

GROUP 2. ANGLES AND ELBOWS FOR TRUNK DUCTS. INSIDE RADIUS 1/2 WIDTH OF DUCT.
A
B
C
D
4 TO 15 = 5
16 TO 27 = 10
28 TO 41 = 15
42 TO 52 = 20
53 TO 64 = 25
4 TO 11 = 10
12 TO 21 = 15
22 TO 27 = 20
28 TO 33 = 25
34 TO 42 = 30
43 TO 51 = 40
52 TO 64 = 50
4 TO 8 = 20
7 TO 11 = 40
12 TO 15 = 55
16 TO 21 = 75
22 TO 27 = 100
28 TO 33 = 125
34 TO 42 = 150
4 TO 11 = 15
12 TO 21 = 20
22 TO 27 = 25
28 TO 42 = 40
E
F
G
H
5 SQ. FT.
10 SQ. FT.
30 SQ. FT.
15 SQ. FT.

Figure 5. Duct Fittings.

Figure 6 illustrates various types of trunk duct take offs and the resistance associated with each. Those requiring two 90° turns in the direction of air flow (A, C, and F) have higher resistances than those with only one turn. B and G illustrate the differences in resistance between a tapered takeoff and one without a taper. Takeoffs at angles of less than 90° have lower resistance.

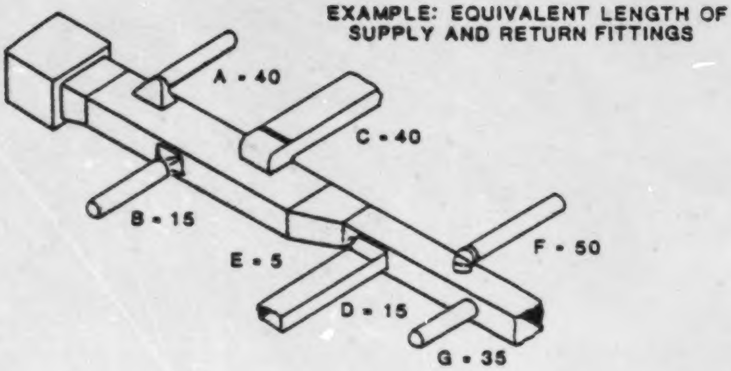


Figure 6. Trunk Duct Takeoffs.

DUCT DESIGN

AIR VELOCITY

The noise level of a duct system is a function of the air velocity in the ducts. Lower air velocities result in lower noise levels, reduced friction losses, and greater system efficiencies. However, lower velocities also require larger ducts to deliver the same volume of air. This increases inital cost and space requirements. In many cases, smaller, high velocity ducts are more economical – even though more power is required for air delivery.

Duct systems are classified as either low velocity or high velocity. Table 2 lists the recommended and maximum velocities for various parts of low velocity systems. High velocity ducts are used in some large distribution systems. High velocity air is not delivered directly to the conditioned

TABLE 2.

RECOMMENDED AND MAXIMUM DUCT VELOCITIES FOR LOW VELOCITY SYSTEMS.

	Recommended Velocities, fpm		
Designation	Residences	Schools, Theaters, Public Buildings	Industrial Buildings
Outdoor Air Intakes	500	500	500
Filters	250	300	350
Heating Coils	450	500	600
Cooling Coils	450	500	600
Air Washers	500	500	500
Fan Outlets	1000-1600	1300-2000	1600-2400
Main Ducts	700-900	1000-1300	1200-1800
Branch Ducts	600	600-900	800-1000
Branch Risers	500	600-700	800
	Maximum Velocities, fpm		
Outdoor Air Intakes	800	900	1200
Filters	300	350	350
Heating Coils	500	600	700
Cooling Coils	450	500	600
Air Washers	500	500	500
Fan Outlets	1700	1500-2200	1700-2800
Main Ducts	800-1200	1100-1600	1300-2200
Branch Ducts	700-1000	800-1300	1000-1800
Branch Risers	650-800	800-1200	1000-1600

space, but to a low velocity duct system that distributes air to individual spaces. Table 3 lists the maximum air velocities for high velocity systems.

TABLE 3.
RECOMMENDED MAXIMUM DUCT VELOCITIES
FOR HIGH VELOCITY SYSTEMS.

cfm Carried by the Duct	Maximum Velocities fpm
60,000 to 40,000	6,000
40,000 to 25,000	5,000
25,000 to 15,000	4,500
15,000 to 10,000	4,000
10,000 to 6,000	3,500
6,000 to 3,000	3,000
3,000 to 1,000	2,500

One of three methods is employed in the design of duct systems.

VELOCITY REDUCTION METHOD

Figure 7 illustrates the velocity reduction method of duct design. Velocities are selected using Table 2 or 3. Fan output velocity is selected first, and ducts are designed to reduce the velocity by arbitrary amounts in succeeding duct sections to bring velocities within the ranges specified

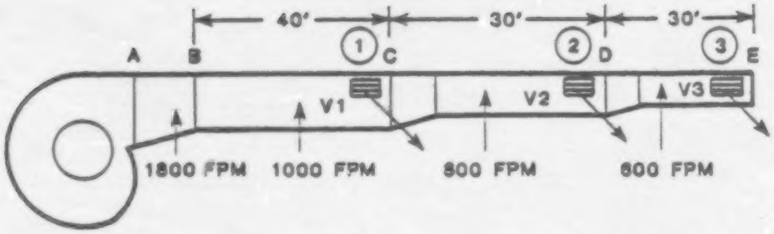


Figure 7. Velocity Reduction Method.

in the tables. This method follows no set rules. Therefore, it is usually employed only by duct designers who have developed a "feel" for duct and velocity requirements.

EQUAL FRICTION METHOD

In the equal friction method, each section of duct is designed to have the same friction loss per foot of duct. This method is the most popular for low velocity systems, both from supply and return ducts. The equal friction method is superior to the velocity reduction method, since it requires less balancing for symmetrical duct layouts and usually results in more economical duct sizes.

STATIC REGAIN METHOD

The static regain method of duct design is used for high velocity systems only. It makes use of the fact that static pressure increases when velocity pressure decreases. The ducts leaving the central station are relatively small, high velocity ducts with high velocity pressure and low static pressure. As the ducts branch, the total area of the duct system increases. The air slows down and the static pressure increases at a rate that overcomes friction losses. This is particularly advantageous for high velocity installations with long duct runs and many takeoffs, or terminal units. Initial savings result not only from reduced duct costs, but also from a reduction in clearance required between floors of buildings. One disadvantage of the static regain method is that large ducts are required at the ends of long runs. In many systems, the ducts become larger near the ends, instead of smaller.

AIR OUTLETS

AIR FLOW PATTERNS

Comfort conditioning requires that air be delivered to the conditioned space in such a manner that it mixes with the room air, providing even temperature distribution and comfortable air velocities in the conditioned space. Velocities of less than 15 fpm may cause a feeling of stagnation, while velocities of greater than 65 fpm produce drafts. Air velocities of 25 to 35 fpm in the occupied zone are considered to be the most comfortable.

Air is generally delivered at a much greater velocity, mixes with room air, and is reduced in velocity before reaching occupants. This is accomplished by the proper selection and location of discharge grills. Grills may be located in the ceiling, on the floor, high in the wall, or low in the wall.

Figure 8 shows the air flow pattern for cooling with a high wall grill. This is the most desirable arrangement for cooling, since cool air mixes with room air and no stagnation occurs. Figure 9 shows the air flow pattern for the same system during heating operation. The lower density hot air tends to remain near the ceiling, and stagnation occurs near

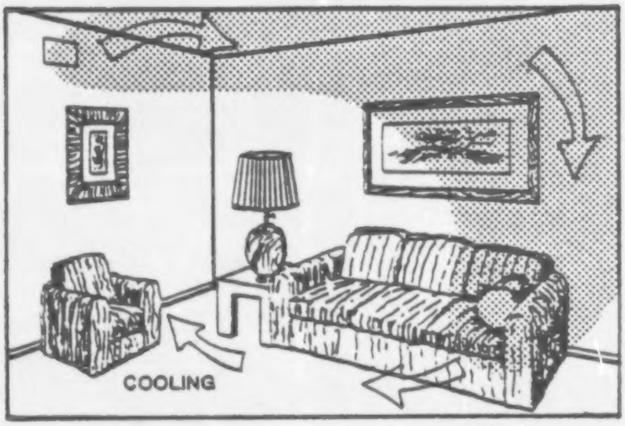


Figure 8. Air Flow Pattern for Cooling.

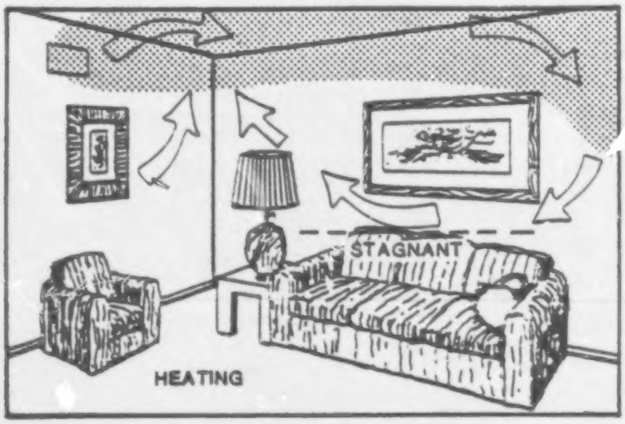


Figure 9. Air Flow Pattern for Heating.

the floor, resulting in cold floors and inefficient heating of room air. For these reasons, high wall outlets are often chosen when the space requires cooling more often than heating.

Figure 10 shows the cooling pattern for ceiling outlets. The grill is designed to spread cool air over the ceiling. The greater density of the cool air aids in air flow downward near the walls and no stagnation occurs. The heating air flow pattern of ceiling outlets is shown in Figure 11.

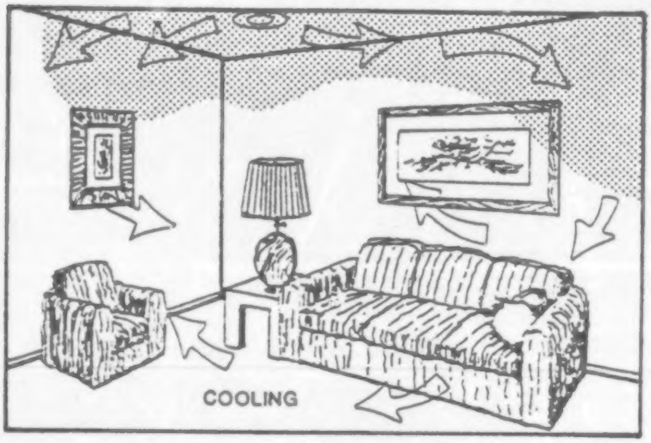


Figure 10. Cooling Pattern for Ceiling Outlets.

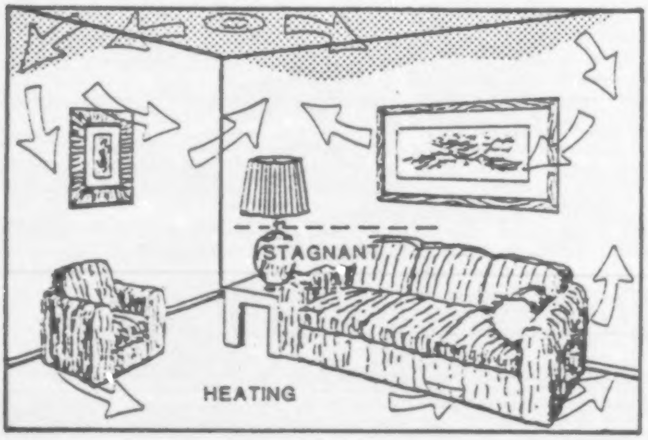


Figure 11. Cooling Pattern for Ceiling Outlets.

As with high wall outlets, hot air tends to remain near the ceiling, resulting in stagnation and cold floors. Ceiling outlets are generally unsatisfactory for spaces with high heating loads and low cooling loads.

Figures 12 and 13 show cooling and heating air flow patterns for floor outlets. During cooling operation, cool air rises to the ceiling because of its exit velocity and

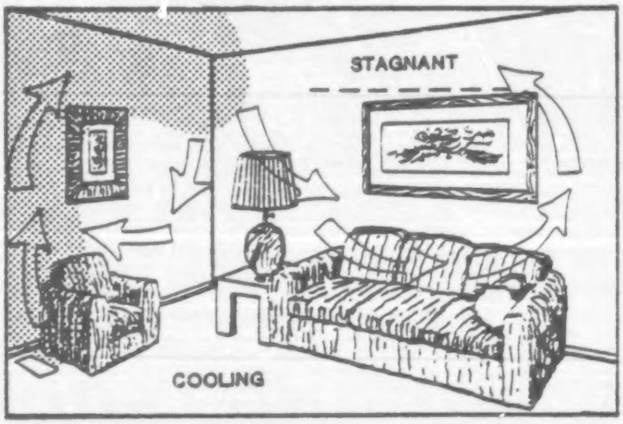


Figure 12. Cooling Air Flow Pattern for Floor Outlets.

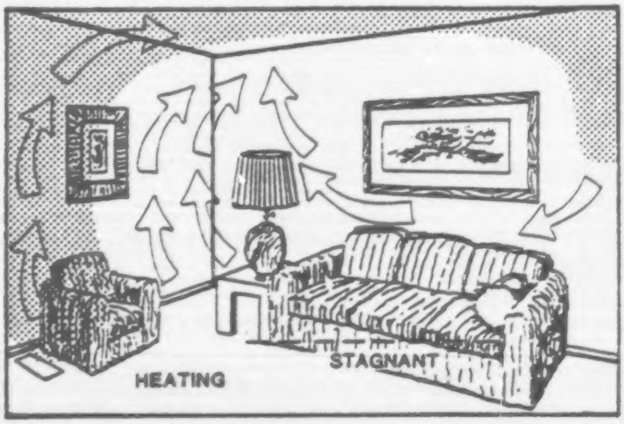


Figure 13. Heating Air Flow Pattern for Floor Outlets.

drops back toward the floor. This produces a stagnation zone near the ceiling, but little stagnation in the occupied zone. During heating operations, there is a small stagnation zone near the floor. Floor grills are available in either spreading or nonspreading designs. Nonspreading grills provide better cooling service, while the spreading design is better-suited for heating service. Floor grills provide the best comfort when heating and cooling loads for a space are balanced.

Figures 14 and 15 illustrate air flow patterns of low wall mounted grills. These provide the most comfortable heating service, but they should not be used for cooling service. This is because the cold air remains near the floor, producing a large stagnation zone in the upper portion of the occupied area.

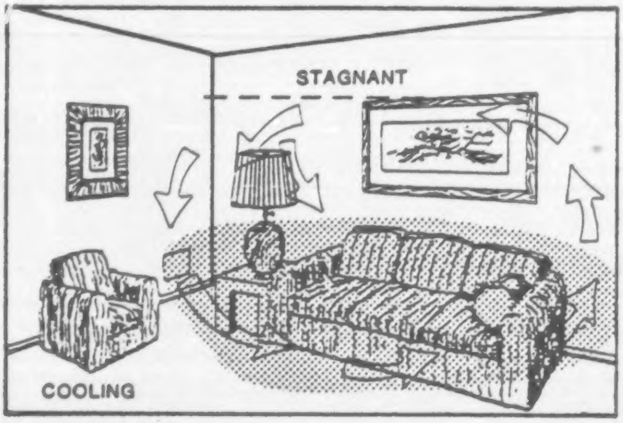


Figure 14. Cooling Air Flow Pattern of Low Wall Mounted Grill.

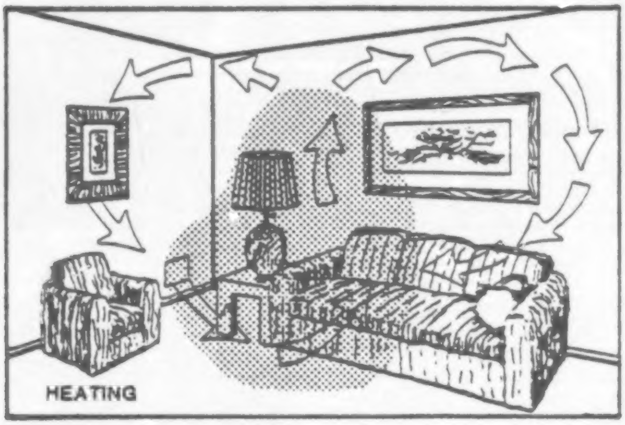


Figure 15. Heating Air Flow Pattern
of Low Wall Mounted Grill.

OUTLET TYPES

Air outlets are grouped into four main classifications. Group A consists of spreading floor-mounted grills. Group B consists of nonspreading floor outlets. High wall and ceiling grills have similar characteristics and are grouped together as Group C. Low wall grills form Group D. Each of these groups is pictured in Figure 16. Table 4 lists air outlet characteristics and applications.

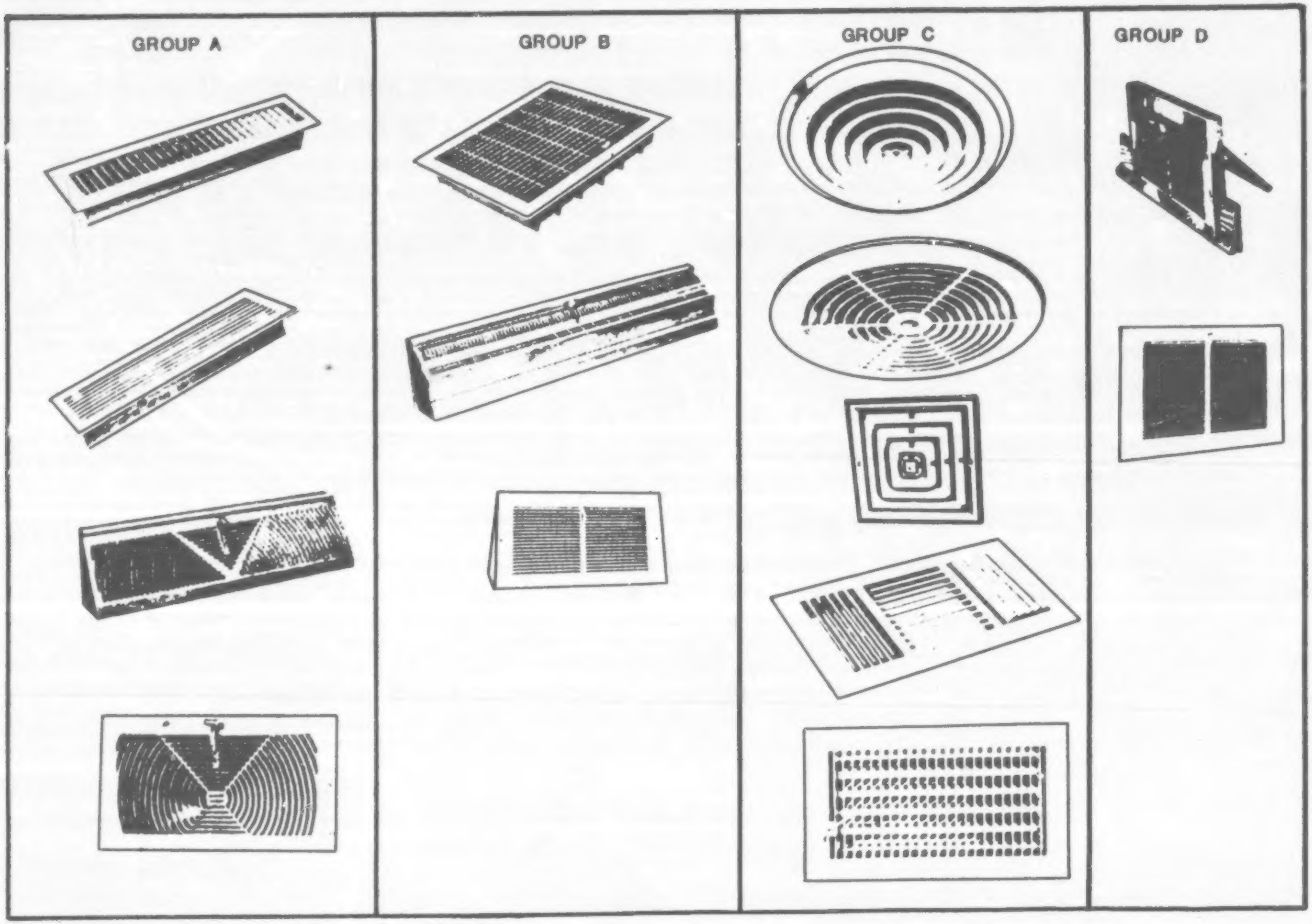

GROUP A
GROUP B
GROUP C
GROUP D

Figure 16. Classification of Air Outlets.

TABLE 4.
GENERAL CHARACTERISTICS OF OUTLETS.

Group	Outlet Flow Pattern	Outlet Type	Most Effective Application	Preferred Location	Size Determined by
A	Vertical Spreading	Floor diffusers, baseboard, and	heating and cooling	Along exposed perimeter	Minimum supply velocity – differs with type and acceptable temperature differential
B	Vertical, Nonspreading	Floor registers, baseboard, and low sidewall	cooling and heating	Not critical	Maximum acceptable heating temperature differential
C	High Horizontal	Ceiling and high sidewall	cooling	Not critical	Major application - whether heating or cooling
D	Low Horizontal	Baseboard and low sidewall	heating only	Long outlet at perimeter short outlet, not critical	Maximum supply velocity should be less than 300 ft/min. (Not recommended for cooling.)

FANS AND BLOWERS

CENTRIFUGAL BLOWERS

Centrifugal fans are used to move air through ducts because these fans are quiet and can move air efficiently against pressure. Figure 17 shows the blade of a radial blade fan and the motion imparted to the air by the blade. Motion produced because of wheel rotation is tangential to the wheel. The component of motion imparted by the shape of the blade depends on blade design. The radial blade fan shown here is used for handling abrasives and dust, but is not used in HVAC applications.

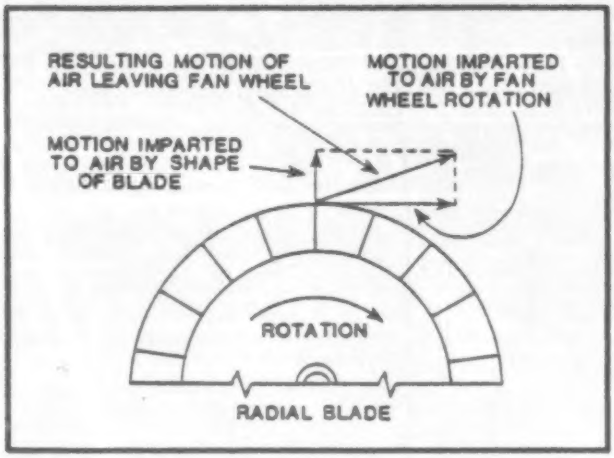

RESULTING MOTION OF AIR LEAVING FAN WHEEL
MOTION IMPARTED TO AIR BY FAN WHEEL ROTATION
MOTION IMPARTED TO AIR BY SHAPE OF BLADE
ROTATION
RADIAL BLADE

Figure 17. Radial Blade Fan.

Figure 18 shows a typical air conditioner blower with forward curved blades. The resultant force on the air for

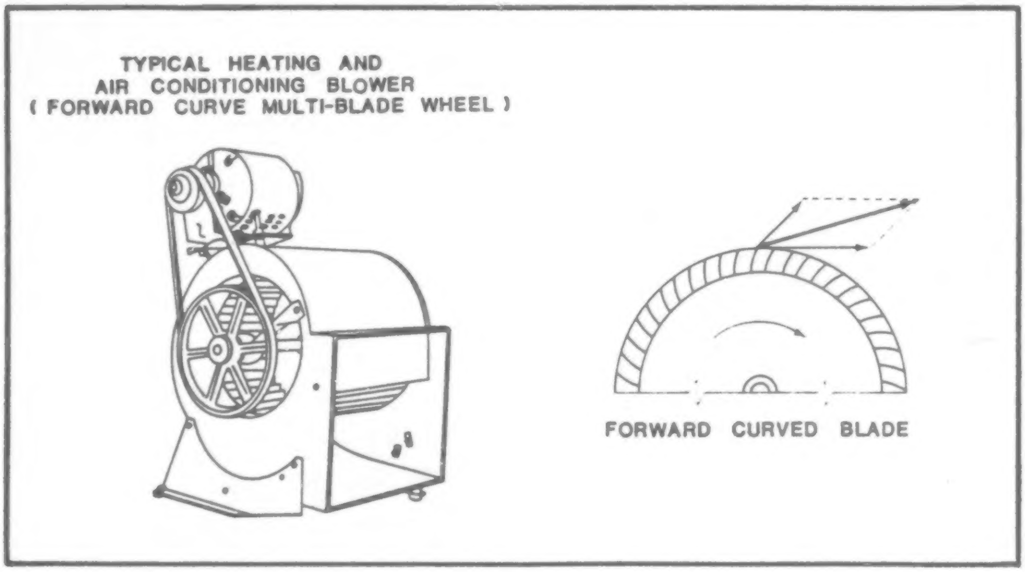

TYPICAL HEATING AND AIR CONDITIONING BLOWER (FORWARD CURVE MULTI-BLADE WHEEL)
FORWARD CURVED BLADE

Figure 18. Forward Curve Multi-Blade Wheel.

this blade shape is also shown. This type of fan moves large masses of air at low rpm and medium pressure with little noise. Most residential and small commercial air conditioners use forward curved fans.

Figure 19 is a backward inclined blade. The blades may be either flat, as shown here, or curved. This fan operates at higher speeds and efficiencies than the forward curved fan and is found in many larger installations.

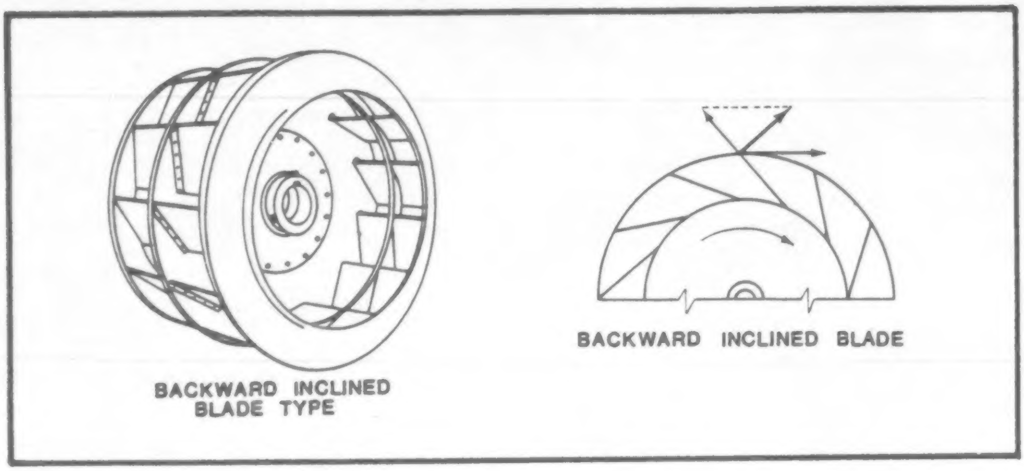


Figure 19. Backward Inclined Blade Wheel.

Either forward or backward blades may have the airfoil shape shown in Figure 20. The airfoil shape of the forward inclined blade produces a more forward force vector and thus an increased pressure for high pressure applications at relatively slow speeds. Air foil blades are more efficient but are only used on large equipment because of higher manufacturing costs. Large backward inclined airfoil fans are the most efficient, and are widely used in larger installations.

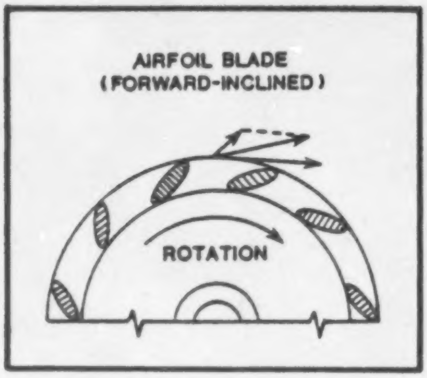

AIRFOIL BLADE
(FORWARD-INCLINED)
ROTATION

Figure 20. Air Foil Blade Wheel.

Such a fan is shown in Figure 21. This figure also lists the names applied to various parts of the fan.

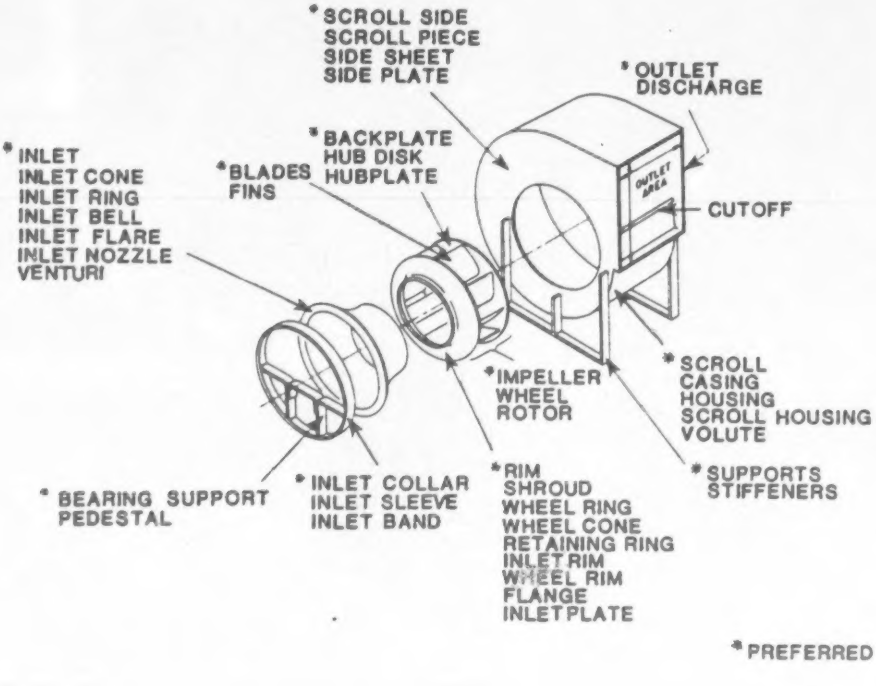
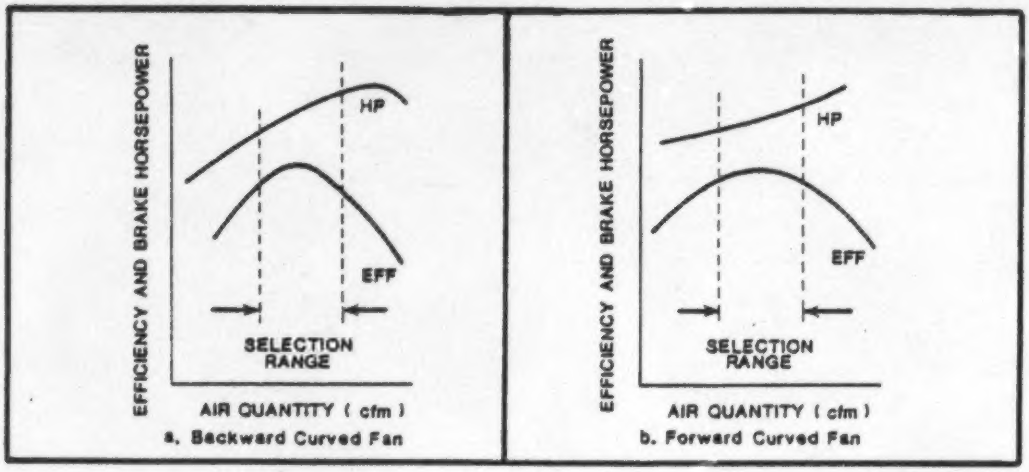

*SCROLL SIDE
SCROLL PIECE
SIDE SHEET
SIDE PLATE
*OUTLET
DISCHARGE
*INLET
INLET CONE
INLET RING
INLET BELL
INLET FLARE
INLET NOZZLE
VENTURI
*BLADES
FINS
*BACKPLATE
HUB DISK
HUBPLATE
OUTLET AREA
CUTOFF
*IMPELLER
WHEEL
ROTOR
*SCROLL
CASING
HOUSING
SCROLL HOUSING
VOLUTE
*BEARING SUPPORT
PEDESTAL
*INLET COLLAR
INLET SLEEVE
INLET BAND
*RIM
SHROUD
WHEEL RING
WHEEL CONE
RETAINING RING
INLET RIM
WHEEL RIM
FLANGE
INLET PLATE
*SUPPORTS
STIFFENERS
*PREFERRED

Figure 21. Common Names Associated with Centrifugal Fan Components.

Figure 22 compares the performance characteristics of the two major fan types. The backward curved fan has a non-overloading characteristic curve. This means that at high delivery rates, the fan power requirement drops and the motor driving the fan cannot overload. The forward curved fan power increases with increasing air quantity. This is considered to be overloading, because the same motor that operates the fan when connected to its duct system may be overloaded if the fan is run while disconnected from the ducts.



a. Backward Curved Fan

b. Forward Curved Fan

Figure 22. Fan Types.

Ideally, fans are operated at the point of highest efficiency and minimum horsepower, but this condition is not always achieved. The acceptable selection ranges of the two types is shown in Figure 22. The backward curved fan offers the highest efficiency, but has a narrower selection range. Tolerance between the inlet bell of the backward curved blades is very critical for high efficiency operation, while the forward curved fan requires no inlet bell. For these reasons, forward curved fans are more ecomonical for general purpose use and smaller units.

PROPELLER FANS

Propeller fans operate at higher speeds than centrifugal fans and are much noiser. Propeller fans are never used with duct systems, but are often employed in cooling towers and condensers. Figure 23 is a vaneaxial fan often used as an exhaust fan. Such fans are simple and relatively inexpensive; the higher noise level is usually not objectional in industrial exhaust applications.

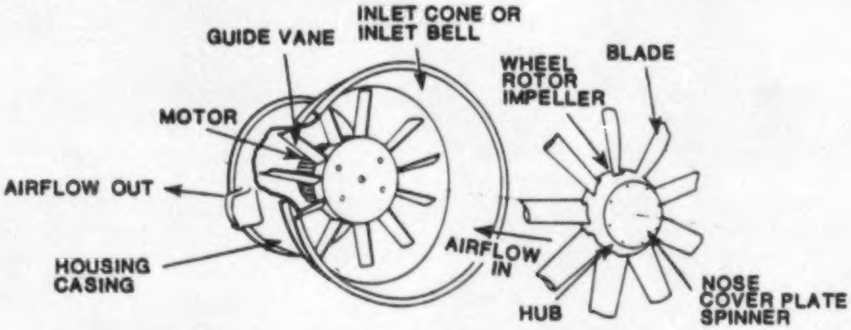

INLET CONE OR
INLET BELL
GUIDE VANE
WHEEL
ROTOR
IMPELLER
BLADE
MOTOR
AIRFLOW OUT
AIRFLOW
IN
HOUSING
CASING
HUB
NOSE
COVER PLATE
SPINNER

Figure 23. Common Names Associated with Axial Fan Components.

FAN CLASSIFICATIONS

Fans are classified according to the operation limits of total pressure. Fan classes include:

- Class I fans – 3 3/4" maximum total pressure.
- Class II fans – 6 3/4" maximum total pressure.
- Class III fans – 12 1/4" maximum total pressure.
- Class IV fans – greater than 12 1/4" total pressure.

Most fans in HVAC service are Class I or Class II, but higher pressure fans are sometimes used in high pressure systems.

SYSTEM APPLICATIONS

Large air conditioning systems vary greatly in both their central stations and ductwork. Each system is, in fact, designed to meet the needs of the particular structure or space it serves. The central station of low pressure systems may be either the blow-through type (in which the fan forces the air through the water coils and then into the ducts) or the draw-through type (in which the fan draws the air through the coils and introduces it directly into the duct system). High pressure systems are almost always of the draw-through type. The following paragraphs describe several common configurations.

SINGLE ZONE CONSTANT VOLUME

The ductwork of a single zone constant volume system (Figure 24) consists of a single duct with branches carrying air to individual spaces. This system can deliver either heating or cooling to the entire zone, but the same temperature air goes to the entire zone at a constant delivery rate.

Figure 25 shows a similar system with remote duct heaters. This system delivers constant volume and temperature air to all zones, but some zones use electric duct heaters to supply additional heat if needed.

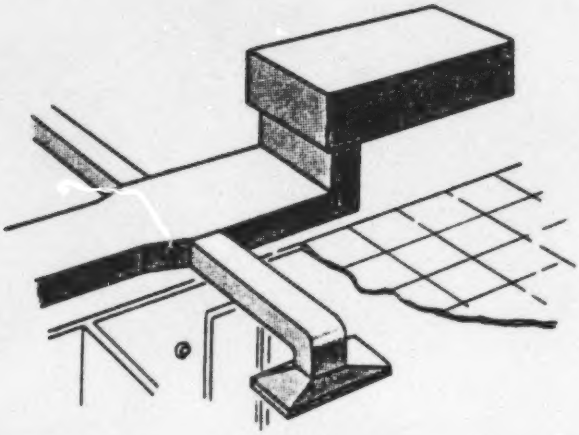


Figure 24. Single Zone Heating/Cooling Constant Volume.

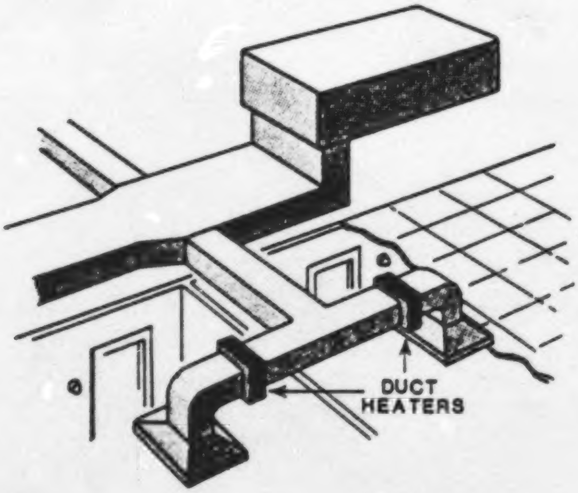


Figure 25. Single Zone Remote Duct Heaters Constant Volume.

SINGLE ZONE VARIABLE VOLUME

A single zone variable volume system (Figure 26) consists of a single duct run with branches to individual spaces. Each branch has a variable column control box and from one to four air diffusers mounted in the ceiling. A temperature-operated damper in the control box controls the volume of conditioned air entering each space. Excess air is exhausted into the ceiling plenum and returned to the central station.

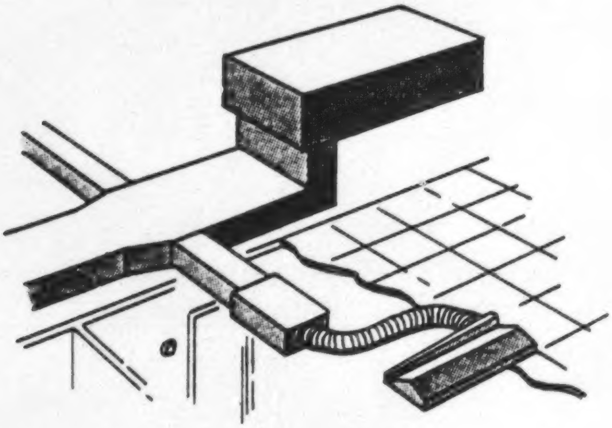


Figure 26. Single Zone Variable Volume.

MULTIZONE CONSTANT VOLUME

In most large buildings, some outer zones require cooling, while others require heating. Interior zones always require cooling because of the heat load of machinery and occupants. The multizone constant volume system (Figure 27) is popular for this application because it can deliver heat to some zones while cooling others. The central station contains

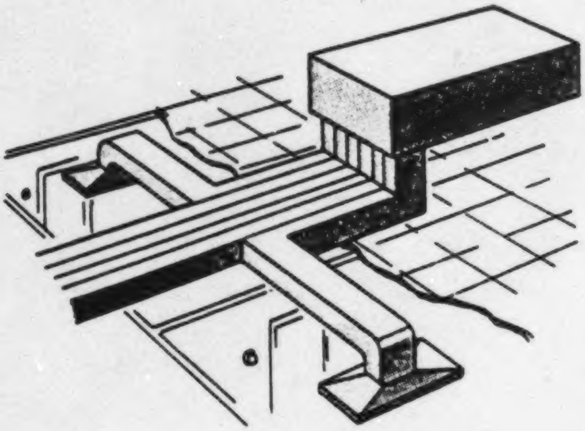


Figure 27. Multizone Heating/Cooling
Constant Volume.

both heating and cooling coils, and air is divided between them. Only one coil is in operation at a time, since outside air is used for cooling in winter and heating in summer.

Each zone is served by a separate duct run, and dampers in the central station direct either heated or cooled air into the duct according to the needs of the individual zone. (Refer to Module HC-02, "System Types," for a detailed diagram of the central station of a multizone system.)

DUAL DUCT

Figure 28 shows the ducts of a dual duct system. This system has two supply ducts to each zone. One carries hot air and the other carries cooled air. The hot and cold air are mixed in a mixing box at each zone. Such systems have high velocities and pressures as high as 6 inches of water.

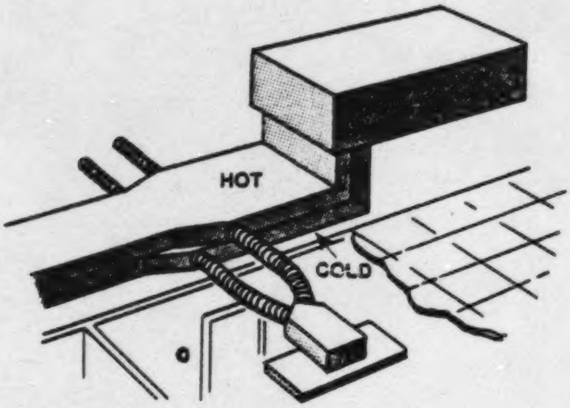


Figure 28. Double-Duct Heating/Cooling Variable Volume.

Installation cost is high, because of the complicated duct system; however, the dual duct system provides the best comfort conditioning available.

RETURN AIR SYSTEMS

Many residential and small commercial systems do not have return air ducts. Return air is drawn directly from the conditioned space into the central station intake. Larger systems return air by a duct system that is similar to the delivery duct system. All return systems are low pressure ducts. Large systems employ return air fans to move the air through the return ducts.

SUMMARY

Air-handling equipment in a typical air conditioning system includes a centrifugal supply air fan that forces conditioned air to the conditioned space through a system of ducts. The power required to deliver the air depends greatly upon the care taken in reducing the friction of the duct system. When conditioned air enters the space, it must be mixed with room air to provide even temperature and adequate air movement. In all but the smallest systems, room air is returned to the central station by a system of ducts that may incorporate a return air fan.

EXERCISES

1. Draw a diagram showing variations in static pressure, velocity pressure, and total pressure in a duct system consisting of a straight piece of duct with an abrupt reduction in size to a smaller straight duct followed by a 90° elbow.
2. A 10" x 10" square duct 80' long has an air velocity of 600 fpm. Determine the volume flow rate and the friction loss of the duct.
3. 3000 ft^3/min of air must be moved a distance of 250' with a velocity of 1000 fpm. Determine the size of duct necessary and the friction loss.
4. Describe the group of air outlets best suited for the following applications:
   a. Heating only.
   b. Cooling only.
   c. Balanced heating and cooling.
5. Make a chart comparing the characteristics and applications of forward curved and backward curved fans.
6. Draw diagrams of the main supply ducts and branch ducts of the following system types:
   a. Single zone constant volume.
   b. Single zone variable volume.
   c. Multizone constant volume.
   d. Dual duct.

LABORATORY MATERIALS

Notebook or clipboard.
Pen or pencil.
Notes from lab in Modules HC-02, "System Types"; and HC-03, "Refrigeration Equipment."

LABORATORY PROCEDURES

This laboratory consists of the last of four field trips to a large central air conditioning installation. The purpose of this visit is to examine the air-handling equipment and piping system. At the end of this laboratory, the student will prepare a detailed schematic of the entire system.

1. Observe the system's air-handling equipment during the tour. Record in the field notebook the data specified in the Data Table and any other information available concerning the system. Examine any schematics or diagrams of the system that are available. (Equipment manufacturer's catalogs may also be helpful.)
2. Check diagrams of the central air handling equipment from Module HC-02, "System Types," and make any necessary corrections or additions.
3. Sketch diagrams of the following components of the air-handling equipment:
   a. Main supply duct layout.
   b. Ducts from main supply to air outlets.
   c. Air outlets.
   d. Return air duct layout.
4. Check and revise the piping diagrams from previous modules. Note all pipe sizes and valve types, and specify which pipes are insulated and which are not. Include diagrams of the pipe support structures.
5. After the field trip, consolidate all data and drawings from all four trips into one report describing the entire system. Correct or redraw diagrams as necessary. Write a brief system analysis describing the good and bad points of the system.

DATA TABLE

FAN CHARACTERISTICS:

Fan	Pressure in w.c.	Velocity fpm	Delivery rate cfm	Horsepower	Manufacturer	Model Number	Blade Type
Supply air							
Return air							
Exhaust							
Ventilation							

AIR DUCTS:

List the dimension and air velocities of each size duct in the supply air systems.

Supply air:

Return air:

REFERENCES

Air Conditioning and Regrigeration Institute. Refrigeration and Air Conditioning. Englewood Cliffs, NJ: Prentice-Hall, Inc. 1979.

Althouse, Andrew D.; Turnquist, Carl H.; and Bracciano, Alfred F. Modern Refrigeration and Air Conditioning. Homewood, IL: The Goodheart-Willcox Co., Inc., 1979.

Carrier Air Conditoning Company. Handbook of Air Conditoning System Design. NY: McGraw-Hill Book Co., 1965.

Howell, Ronald H., and Sauer, Harry J., Jr. Environmental Control Principles. NY: American Society of Heating, Refrigerating, and Air Conditioning Engineers.

TEST

1. If a duct with no branches is reduced in size, the...
   - a. total pressure remains the same.
   - b. static pressure decreases.
   - c. the velocity pressure increases.
   - d. All of the above.
   - e. Only b and c are true.
2. If a duct of constant size makes a 90° bend, the...
   - a. velocity pressure decreases.
   - b. static pressure decreases.
   - c. total pressure decreases.
   - d. All of the above.
   - c. Only b and c are true.
3. Which of the following systems is most likely to have the central station?
   - a. Single zone constant volume.
   - b. Single zone variable volume.
   - c. Multizone constant volume.
   - d. Dual duct.
   - e. None; such conditions do not exist.
4. If the air velocity in a duct is doubled, the friction loss...
   - a. remains the same.
   - b. increases slightly.
   - c. doubles.
   - d. more than doubles.

5. For systems providing both heating and cooling service, the best air outlet is the...
   a. low wall outlet.
   b. ceiling outlet.
   c. high wall outlet.
   d. floor outlet.
   e. There is no real difference.

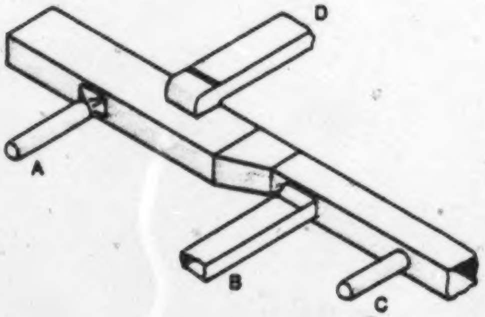
6. The most common duct design method is the...
   a. static regain method.
   b. velocity reduction method.
   c. equal friction method.
   d. total pressure method.
   e. hit or miss method.

7. Fans with forward curved blades...
   a. run at higher velocities than fans with backward curved blades.
   b. are seldom used in small systems.
   c. have higher efficiencies than fans with backward curved blades.
   d. are not suitable for high pressure systems even with airfoil blades.
   e. None of the above.

8. Vaneaxial fans are not used in supply air systems with ducts because...
   a. they are too expensive.
   b. they are too noisy.
   c. their air pressure is too high.
   d. Only a and b.
   e. Only b and c.

9. A large building with offices on the outside and equipment rooms in the interior...
   a. will probably have a dual duct system.
   b. will probably have multizone system.
   c. will require no heat for interior zones.
   d. Only a and c are true.
   e. Only b and c are true.

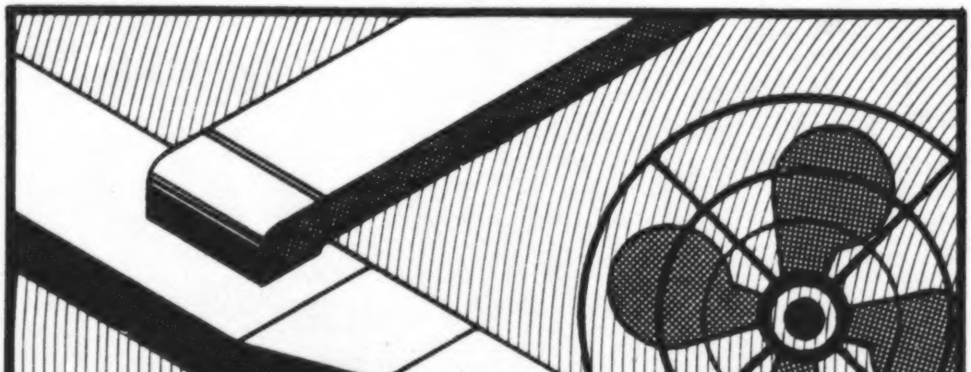
10. Which of the branch takeoffs in the following diagram has the lowest resistance?
   a. A
   B. B
   c. C
   d. D
   e. A and B
   f. B and D



ENERGY TECHNOLOGY

CONSERVATION AND USE

HEATING, VENTILATING, AND AIR CONDITIONING



MODULE HC - 08

PSYCHROMETRICS

CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

INTRODUCTION

Most heating and air conditioning applications require that temperature and relative humidity are maintained within certain limits. Energy must be supplied or withdrawn to raise or lower temperature, and additional energy must be supplied or withdrawn to evaporate or condense water. Calculations relating change in temperature, change in moisture content of the air, and change in required energy are made with the aid of the psychrometric chart. This chart relates all important quantities used in heating and air conditioning calculations. This module discusses elements of the psychrometric chart, representation of processes on the chart, and use of the chart in solving problems in air conditioning design. The laboratory consists of solving problems using the psychrometric chart.

PREREQUISITES

The student should have completed Module HC-01, "The Basic Refrigeration Cycle."

OBJECTIVES

Upon completion of this module, the student should be able to:

1. Identify the following terms:
    a. Dry-bulb temperature.
    b. Wet-bulb temperature.
    c. Specific humidity.

    - d. Dew-point temperature.
    - e. Relative humidity.
    - f. Specific volume.
    - g. Sensible heat.
    - h. Latent heat.
    - i. Enthalpy.
2. Identify the following elements of the psychrometric chart:
    - a. Dry-bulb temperature lines.
    - b. Specific humidity lines.
    - c. Saturation line.
    - d. Relative humidity lines.
    - e. Wet-bulb temperature lines.
    - f. Enthalpy scale.
    - g. Sensible heat factor scale.
3. Identify the following processes on the chart:
    - a. Heating.
    - b. Cooling.
    - c. Humidifying.
    - d. Dehumidifying.
    - e. Typical comfort heating.
    - f. Typical comfort air conditioning.
4. Given any two of the following quantities, calculate the third:
    - a. Sensible heat load.
    - b. Change in temperature.
    - c. Air flow rate.
5. Given any two of the following quantities, calculate the third:
    - a. Latent heat load.
    - b. Change in specific humidity.
    - c. Air flow rate.

6. Given any two of the following quantities, calculate the third:
   a. Total heat load.
   b. Change in enthalpy.
   c. Air flow rate.
7. Given any two of the following quantities for a sample of air, determine the others using the psychrometric chart:
   a. Dry-bulb temperature.
   b. Wet-bulb temperature.
   c. Specific humidity.
   d. Relative humidity.
   e. Enthalpy.
8. Given air flow rate for two conditions of air and data necessary for locating the two point on the psychrometric chart representing the initial air conditions, determine the condition of the resulting air mixture.
9. Given data concerning an air conditioning process, plot the process on the psychrometric chart and determine the apparatus dew point.

DEFINITION OF TERMS

Air is composed of a mixture of dry gases and water vapor. Air consists of approximately 77% nitrogen and 23% oxygen, with other gases making up less than 1%. Water vapor exists in very small quantities, but is of great importance in heating and air conditioning because of the energy necessary to condense or evaporate water and the necessity for humidity control. Psychrometrics is the analysis of the properties of air in relation to the normal range of temperature and water content that are encountered in heating and air conditioning applications. These properties are determined by using the psychrometric chart. The following terms are used in the chart.

DRY-BULB TEMPERATURE

The actual temperature of the air as measured with an ordinary thermometer.

WET-BULB TEMPERATURE

The temperature of the air as measured with a wet-bulb thermometer. The evaporation of the water from around the bulb lowers its temperature.

MOISTURE CONTENT

The weight of the water vapor in the air expressed in pounds per pound or grains per pound (7000 grains = 1 pound), also called "specific humidity."

DEW-POINT TEMPERATURE

The saturation temperature at which condensation of water vapor to liquid water takes place. As air is cooled, its ability to hold water vapor decreases. At the dew-point, some water begins to condense.

RELATIVE HUMIDITY

The ratio of actual water vapor in the air to the maximum amount that could be present in air of the same temperature, expressed as a percent.

SPECIFIC VOLUME

The volume in cubic feet of one pound of the mixture of air and water vapor.

SENSIBLE HEAT

The amount of dry heat energy in the air expressed in Btu per pound of air. Sensible heat is reflected by the dry-bulb temperature. The sensible heat load of a system is the heat energy added or extracted to produce a temperature change. Sensible heat does not change the water content of the air.

LATENT HEAT

The heat energy required to evaporate the amount of moisture a specific amount of air contains, expressed in Btu per pound. The latent heat load of a system is the heat energy added or extracted to evaporate or condense water. Latent heat does not result in a temperature change; it changes the water content only.

ENTHALPY

The total energy content of the air and water vapor mixture. Enthalpy is the total of the sensible heat and the latent heat. Table 1, on the following page, gives the enthalpy of air as a function of wet-bulb temperature. The total heat load of a system is the energy necessary to change the enthalpy of the air by the desired amount. Enthalpy is the sum of the latent heat load and the sensible heat load.

TABLE 1. ENTHALPY IN Btu PER POUND OF DRY AIR.
(Containing no water droplets.)

Wet-Bulb Temperature F	TENTHS OF A DEGREE									
	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
35	13.01	13.05	13.10	13.14	13.18	13.23	13.27	13.31	13.35	13.40
36	13.44	13.48	13.53	13.57	13.61	13.66	13.70	13.75	13.79	13.83
37	13.87	13.91	13.96	14.00	14.05	14.09	14.14	14.18	14.23	14.27
38	14.32	14.37	14.41	14.46	14.50	14.55	14.59	14.64	14.68	14.73
39	14.77	14.82	14.86	14.91	14.95	15.00	15.05	15.09	15.14	15.18
40	15.23	15.28	15.32	15.37	15.42	15.46	15.51	15.56	15.60	15.65
41	15.70	15.75	15.80	15.84	15.89	15.94	15.99	16.03	16.08	16.13
42	16.17	16.22	16.27	16.32	16.36	16.41	16.46	16.51	16.56	16.61
43	16.66	16.71	16.76	16.81	16.86	16.91	16.96	17.00	17.05	17.10
44	17.15	17.20	17.25	17.30	17.35	17.40	17.45	17.50	17.55	17.60
45	17.65	17.70	17.75	17.80	17.85	17.91	17.96	18.01	18.06	18.11
46	18.16	18.21	18.26	18.32	18.37	18.42	18.47	18.52	18.58	18.63
47	18.68	18.73	18.79	18.84	18.89	18.95	19.00	19.05	19.10	19.16
48	19.21	19.26	19.32	19.37	19.43	19.48	19.53	19.59	19.64	19.70
49	19.75	19.81	19.86	19.92	19.97	20.03	20.08	20.14	20.19	20.25
50	20.30	20.36	20.41	20.47	20.52	20.58	20.64	20.69	20.75	20.80
51	20.86	20.92	20.97	21.03	21.09	21.15	21.20	21.26	21.32	21.38
52	21.44	21.50	21.56	21.62	21.67	21.73	21.79	21.85	21.91	21.97
53	22.02	22.08	22.14	22.20	22.26	22.32	22.38	22.44	22.50	22.56
54	22.62	22.68	22.74	22.80	22.86	22.92	22.98	23.04	23.10	23.16
55	23.22	23.28	23.34	23.41	23.47	23.53	23.59	23.65	23.72	23.78
56	23.84	23.90	23.97	24.03	24.10	24.16	24.22	24.29	24.35	24.42
57	24.48	24.54	24.61	24.67	24.74	24.80	24.86	24.93	24.99	25.06
58	25.12	25.19	25.25	25.32	25.38	25.45	25.52	25.58	25.65	25.71
59	25.78	25.85	25.92	25.98	26.05	26.12	26.19	26.26	26.32	26.39
60	26.46	26.53	26.60	26.67	26.74	26.81	26.87	26.94	27.01	27.08
61	27.15	27.22	27.29	27.36	27.43	27.50	27.57	27.64	27.71	27.78
62	27.85	27.92	27.99	28.07	28.14	28.21	28.28	28.35	28.43	28.50
63	28.57	28.64	28.72	28.79	28.87	28.94	29.01	29.09	29.16	29.24
64	29.31	29.39	29.46	29.54	29.61	29.69	29.76	29.84	29.91	29.99
65	30.06	30.14	30.21	30.29	30.37	30.45	30.52	30.60	30.68	30.75
66	30.83	30.91	30.99	31.07	31.15	31.23	31.30	31.38	31.46	31.54
67	31.62	31.70	31.78	31.86	31.94	32.02	32.10	32.18	32.26	32.34
68	32.42	32.50	32.59	32.67	32.75	32.84	32.92	33.00	33.08	33.17
69	33.25	33.33	33.42	33.50	33.59	33.67	33.75	33.84	33.92	34.01
70	34.09	34.18	34.26	34.35	34.43	34.52	34.61	34.69	34.78	34.86
71	34.95	35.04	35.13	35.21	35.30	35.39	35.48	35.57	35.65	35.74
72	35.83	35.92	36.01	36.10	36.19	36.29	36.38	36.47	36.56	36.65
73	36.74	36.83	36.92	37.02	37.11	37.20	37.29	37.38	37.48	37.57
74	37.66	37.76	37.85	37.95	38.04	38.14	38.23	38.33	38.42	38.52
75	38.61	38.71	38.80	38.90	38.99	39.09	39.19	39.28	39.38	39.47
76	39.57	39.67	39.77	39.87	39.97	40.07	40.17	40.27	40.37	40.47
77	40.57	40.67	40.77	40.87	40.97	41.08	41.18	41.28	41.38	41.48
78	41.58	41.68	41.79	41.89	42.00	42.10	42.20	42.31	42.41	42.52
79	42.62	42.73	42.83	42.94	43.05	43.16	43.26	43.37	43.48	43.58
80	43.69	43.80	43.91	44.02	44.13	44.24	44.34	44.45	44.56	44.67
81	44.78	44.89	45.00	45.12	45.23	45.34	45.45	45.56	45.68	45.79
82	45.90	46.01	46.13	46.24	46.36	46.47	46.58	46.70	46.81	46.93
83	47.04	47.16	47.28	47.39	47.51	47.63	47.75	47.87	47.98	48.10
84	48.22	48.34	48.46	48.58	48.70	48.83	48.95	49.07	49.19	49.31
85	49.43	49.55	49.68	49.80	49.92	50.05	50.17	50.29	50.41	50.54

ELEMENTS OF THE PSYCHROMETRIC CHART

The psychrometric chart is basically a graph of water content, or the air versus dry-bulb temperature with other quantities added. This section discusses the components of the chart. The completed chart is shown in Figure 11.

DRY-BULB TEMPERATURE LINES

The horizontal scale of the chart (Figure 1) is calibrated in degrees Fahrenheit (°F) and represents the dry-bulb temperature. Lines of constant dry-bulb temperature are vertical.

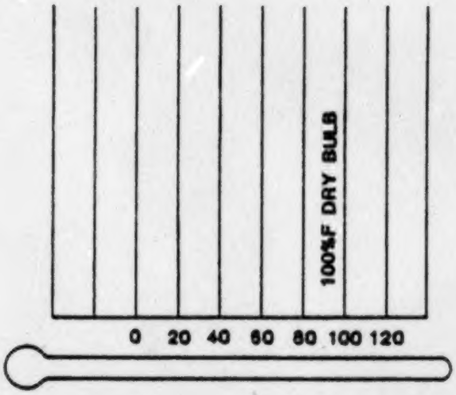


Figure 1. Dry-Bulb Temperature (°F) Lines.

SPECIFIC HUMIDITY LINES

The vertical scale of the chart (Figure 2) is calibrated in both pounds of moisture per pound of dry air and grains of moisture per pound of dry air (Gr/lb), and represents the moisture content or specific humidity. Lines of constant specific humidity are horizontal.

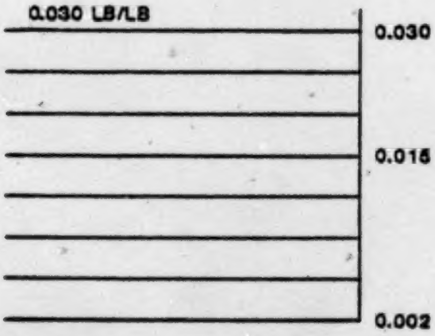


Figure 2. Specific Humidity Lines.

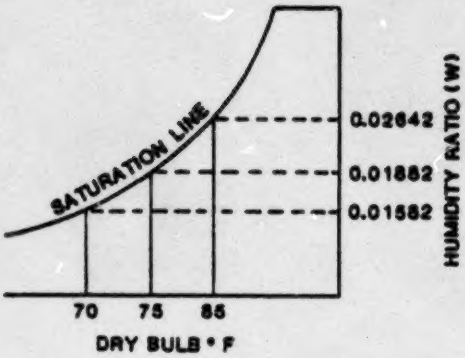


Figure 3. Saturation Line.

SATURATION LINE

At any specific temperature, air can contain only so much water vapor. Plotting the maximum specific volume versus air temperature results in the saturation line shown in Figure 3. Points on this line are called dew points, and the relative humidity at this line is 100%.

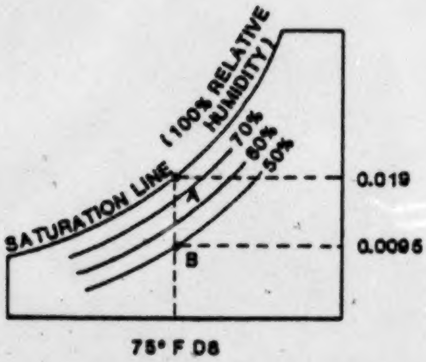


Figure 4. Relative Humidity Line.

RELATIVE HUMIDITY LINES

Figure 4 shows additional relative humidity lines. They have the same general shape as the saturation lines and are provided at 10% intervals.

WET-BULB TEMPERATURE LINES

The wet-bulb temperature lines (Figure 5) slant downward to the right from the saturation line. The wet-bulb temperature scale is located along the saturation line. Along this line, the wet-bulb and dry-bulb temperatures are the same, since 100% relative humidity means that no water will be evaporated from the wet bulb to lower its temperature below that of the dry bulb.

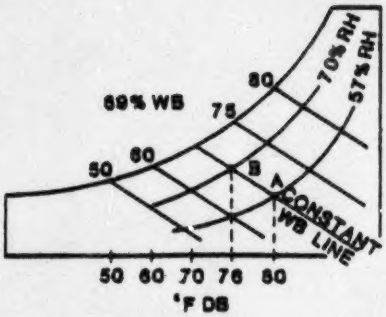

69% WB
80
75
60
50
B
A
70% RH
57% RH
CONSTANT WB LINE
50 60 70 76 80
°F DB

Figure 5. Wet-Bulb Temperature Lines.

SPECIFIC VOLUME LINES

Figure 6 shows lines of specific volume calibrated in cubic feet per pound of air. These are used in fan and air flow calculations, but will not be used in this module.

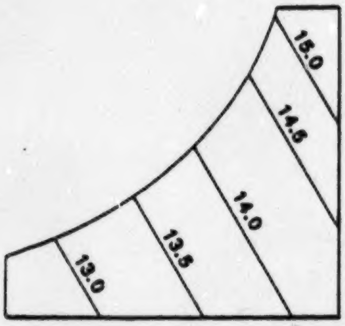

15.0
14.5
14.0
13.5
13.0

Figure 6. Specific Volume Lines.

ENTHALPY SCALE

The enthalpy scale is located above the saturation line as shown in Figure 7. The lines of constant enthalpy correspond to lines of constant wet-bulb temperature. The enthalpy of any point on the chart may be determined by following the wet-bulb temperature line from that point through the saturation line to the enthalpy scale.

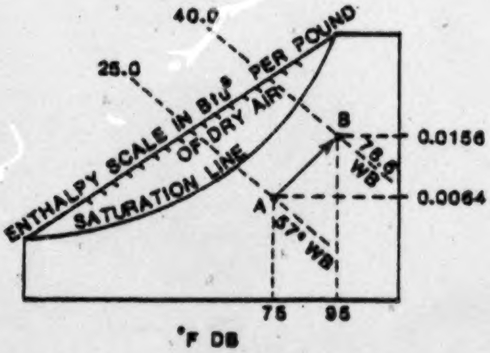

40.0
25.0
ENTHALPY SCALE IN BTU PER POUND OF DRY AIR
SATURATION LINE
B
0.0156
76.6 WB
A
0.0064
57° WB
75
95
°F DB

Figure 7. Enthalpy Lines.

ENTHALPY DEVIATION LINES

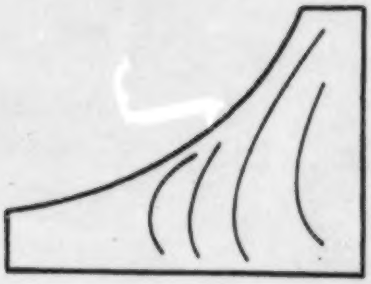


Figure 8. Enthalpy Deviation Lines.

The enthalpy of the air does not actually vary in exact proportion to the wet-bulb temperature. Figure 8 shows enthalpy deviation lines that may be used to correct for the small error introduced by assuming that the constant enthalpy lines are parallel with the wet-bulb temperature lines. The errors are not usually large, and in most cases these lines are not used. In fact, many charts do not show these lines at all. Enthalpy deviation lines will not be used in this module.

SENSIBLE HEAT FACTOR SCALE

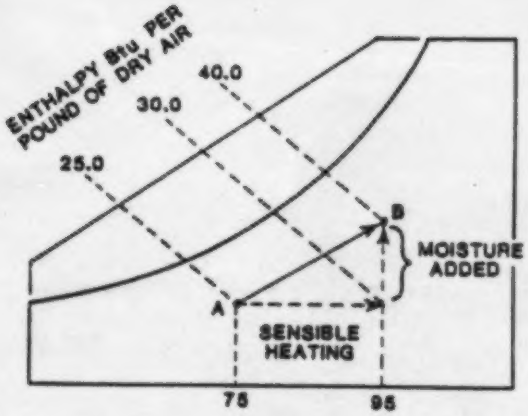


Figure 9. Sensible and Latent Heat.

Figure 9 shows a process that changes the state of the air from Point A to Point B. The process requires that air be heated and water vapor be added. The horizontal displacement represents the sensible heat added in the form of a temperature increase. The vertical displacement represents the latent heat necessary to evaporate the water. The slope of the line from A to B is the ratio of latent heat to the sensible heat. The sensible heat ratio, also called the sensible to total ratio, is defined as the ratio of sensible heat to enthalpy change (total energy change). In Figure 9, the sensible heat added is 5 Btu/lb and the enthalpy change is 15 Btu/lb. Thus, the sensible heat ratio is 0.33.

Figure 10 shows the sensible heat ratio scale. It is used to determine the slope of a line from a point if the sensible heat ratio is known. A line drawn from this scale to the dot located at 80°F (DB) and 50% RH establishes the slope of all lines with that sensible heat ratio. Note that the dot may be located at other points on other charts. This is of no consequence, since the function of this scale is to establish a direction only.

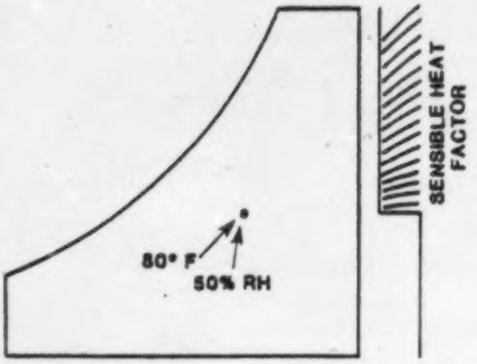


Figure 10. Sensible Heat Factor Scale.

THE COMPLETED CHART

Several styles of psychrometric charts are in common use by different manufacturers, but all psychrometric charts have essentially the same features and all contain the same information. A complete chart is shown in Figure 11. A point representing a specific air condition may be located on the chart if any two of the quantities included in the chart are known. All other quantities may then be read directly from the chart.

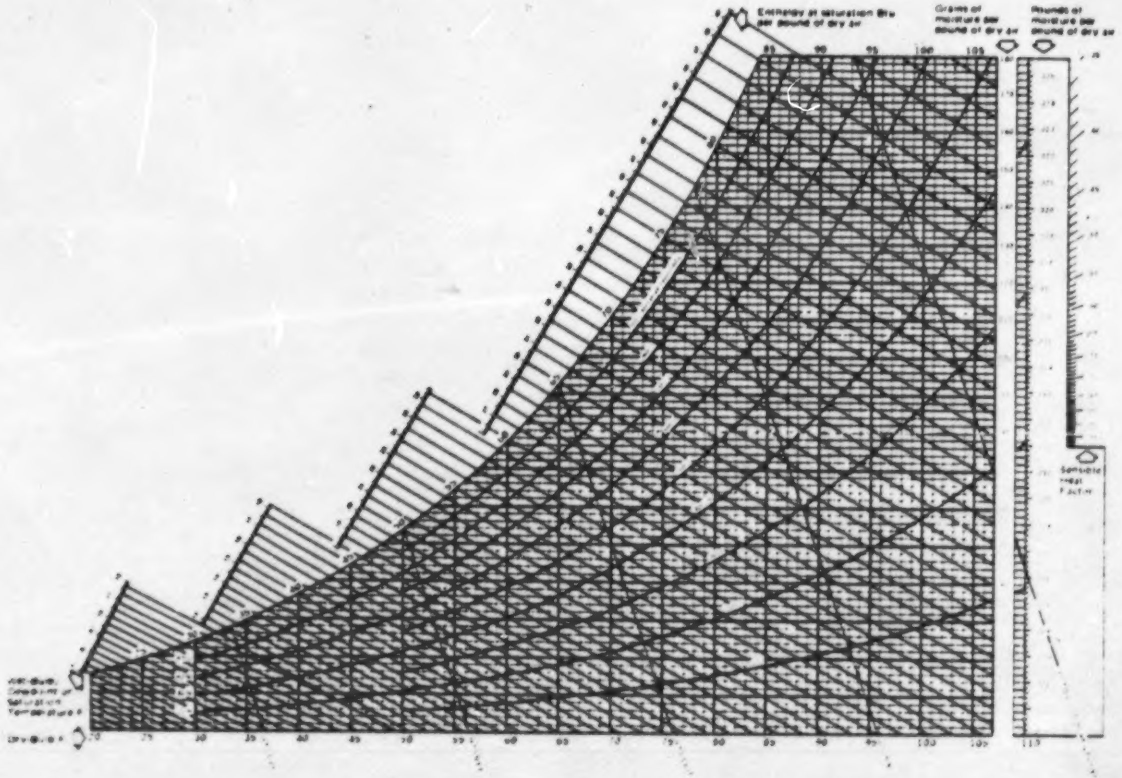


Figure 11. Psychrometric Chart.

PSYCHROMETRIC PROCESSES

All processes in heating and air conditioning may be plotted on the psychrometric chart. Figure 12 shows the processes represented by vertical and horizontal displacement. Movement to the right indicates a temperature increase, but no change in moisture content. Thus, the relative humidity drops and the wet-bulb temperature decreases. Movement to the left indicates cooling, but no change in moisture content. In this case, both the relative humidity and wet-bulb temperature rise. Vertical displacement represents a change in moisture content at a constant temperature. Upward movement indicates an increase in moisture and, thus, an increase in both relative humidity and wet-bulb temperature. Downward movement indicates a decrease in these quantities.

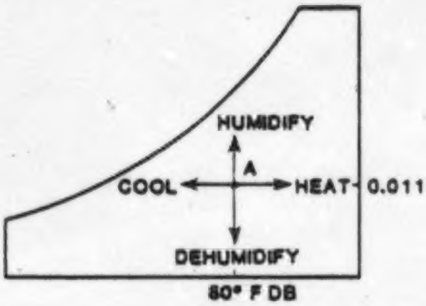


Figure 12. Effects of Moving on the Chart.

HEATING AND COOLING FOR COMFORT

Figure 13 shows the process used for comfort control in winter. If air is merely heated, the relative humidity drops to an uncomfortable level. Thus, additional energy is required to vaporize water in order to maintain a comfortable relative humidity.

Figure 14 shows the process used for comfort control in summer. If the air is merely cooled, the relative humidity rises to an uncomfortable level. Thus, additional energy is required to condense water to maintain a comfortable relative humidity.

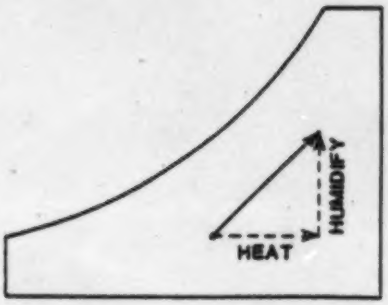


Figure 13. Heating in Winter.

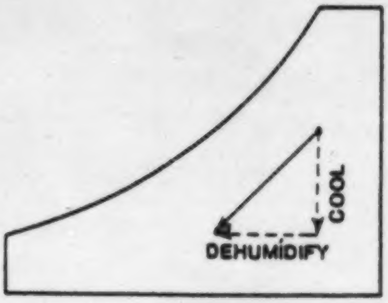


Figure 14. Air Conditioning in Summer.

CALCULATIONS

The data for psychrometric problems are usually given in terms of latent and sensible heat loads in Btu/hr, air flow rate in cubic feet per minute (cfm), and changes in temperature and moisture content. The following equations are often used along with the psychrometric chart to determine heat loads.

$$Q_s = 1.08\ A\Delta T \qquad \text{Equation 1}$$

where:

Q_s = Sensible heat load in Btu/hr.
A = Air flow rate in cfm.
ΔT = Change in dry-bulb temperature.

$$Q_\ell = 0.68\ A\Delta W \qquad \text{Equation 2}$$

where:

Q_ℓ = Latent heat load in Btu/hr.
ΔW = Change in specific humidity in Gr/lb.

$$Q_t = 4.5\ A\Delta H \qquad \text{Equation 3}$$

where:

Q_t = Total heat load.
ΔH = Change in enthalpy in Btu/lb.

Use of these equations is illustrated in Example A, "Calculation of Heat Loads."

EXAMPLE A: CALCULATION OF HEAT LOADS.	
Given:	Air at a temperature (DB) of 60°F with a relative humidity of 40% is heated and humidified to 80° and a relative humidity of 50%. The air flow rate is 2000 cfm.

Example A. Continued.

Find: a. Sensible heat load.

b. Latent heat load.

c. Total heat load.

Solution: From the following psychrometric chart determine the following quantities for the two points.

$T_1 = 60°F$ $T_2 = 80°F$

$W_1 = 31$ Gr/lb $W_2 = 77$ Gr/lb

$H_1 = 19.4$ Btu/lb $H_2 = 31.5$ Btu/lb

$A = 2000$ cfm

a. Sensible heat load.

$$Q_s = 1.08\ A\Delta T$$
$$= (1.08)(2000\ \text{cfm})(80°F - 60°F)$$
$$= (1.08)(2000\ \text{cfm})(20°F)$$
$$Q_s = 43{,}200\ \text{Btu/hr.}$$

b. Latent heat load.

$$Q_\ell = 0.68\ A\Delta W$$
$$= (0.68)(2000\ \text{cfm})(77\ \text{Gr/lb} - 31\ \text{Gr/lb})$$
$$= (0.68)(2000\ \text{cfm})(46\ \text{Gr/lb})$$
$$Q_\ell = 62{,}560\ \text{Btu/hr.}$$

c. Total heat load.

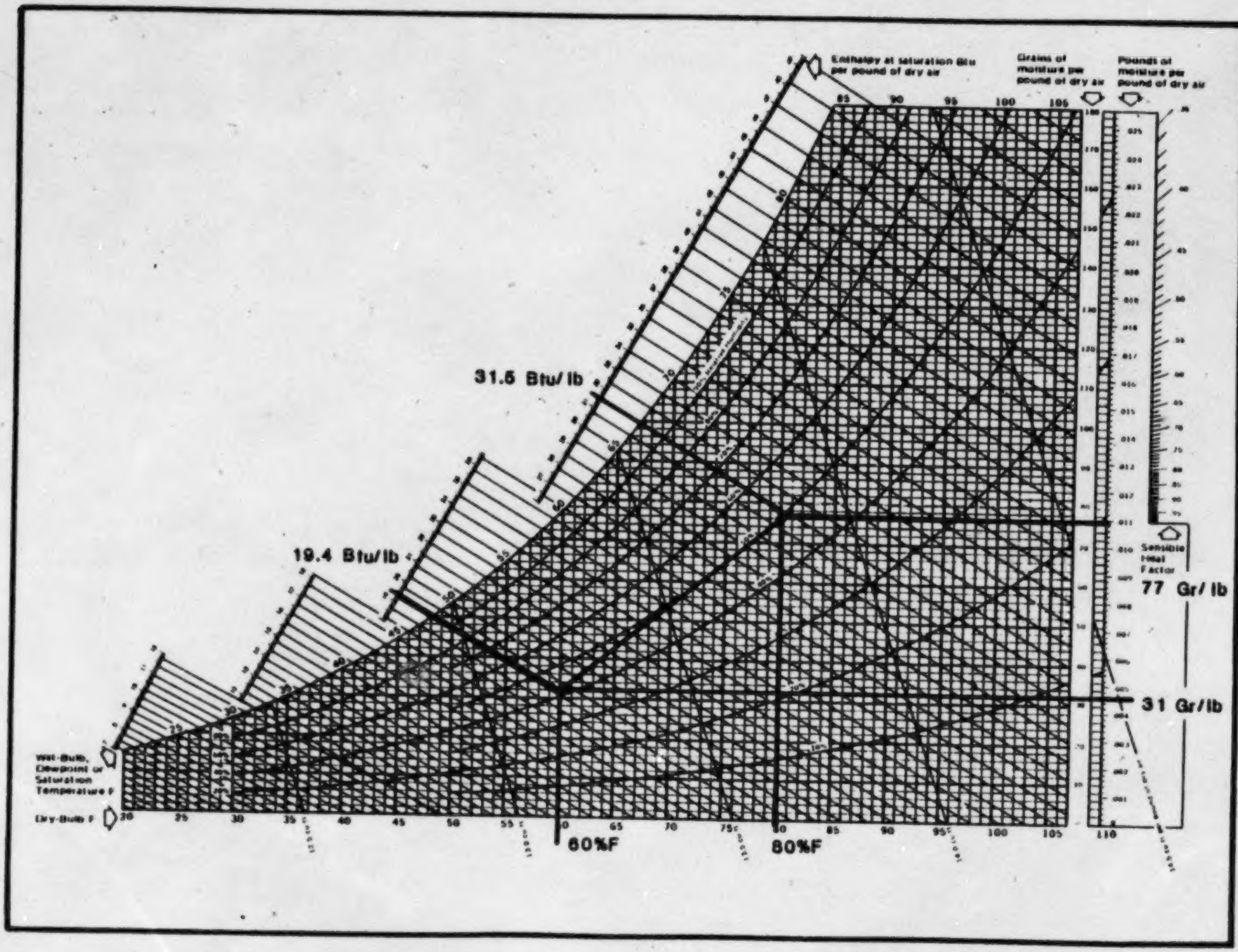
$$Q_t = 4.5\ A\Delta H$$
$$= (4.5)(2000\ \text{cfm})(31.5\ \text{Btu/lb} - 19.4\ \text{Btu/lb})$$
$$= (4.5)(2000\ \text{cfm})(12.1\ \text{Btu/lb})$$
$$Q_t = 108{,}900\ \text{Btu/hr.}$$

Check:

$$Q_s + Q_\ell = 43{,}200\ \text{Btu/hr} + 62{,}560\ \text{Btu/hr}$$
$$Q_s + Q_\ell = 105{,}760\ \text{Btu/hr}$$
$$Q_t = 108{,}900\ \text{Btu/hr.}$$

These values are within the accuracy of the chart.

Example A. Continued.



AIR MIXTURES

Figure 15 shows the result when air of two different conditions is mixed. The conditions of the mixture (Point C) must lie on the line connecting the point representing the conditions of the air mixed (Points A and B). If the ratio of the mixture is known, the location of Point C may be determined by using Equation 4 to determine the temperature of the mixture, or Equation 5 to determine its moisture content.

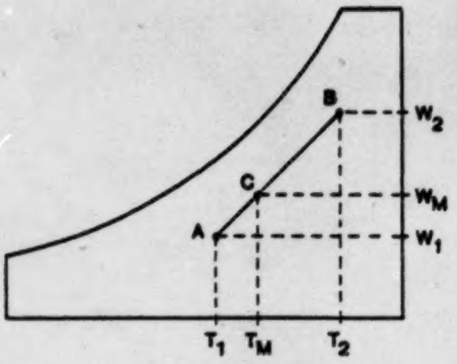


Figure 15. Air Mixtures.

$$T_m = T_1 + \left(\frac{A_2}{A_1 + A_2}\right)(T_2 - T_1) \qquad \text{Equation 4}$$

where:

T_m = Temperature of mixture.
T_1 = Temperature of cool air.
T_2 = Temperature of warm air.
A_1 = Flow rate of cool air.
A_2 = Flow rate of warm air.

$$W_m = W_1 + \left(\frac{A_2}{A_1 + A_2}\right)(W_2 - W_1) \qquad \text{Equation 5}$$

where:

W_1 = Specific humidity of cool air.
W_2 = Specific humidity of warm air.

Example B shows the use of these equations.

EXAMPLE B: TEMPERATURE AND SPECIFIC HUMIDITY OF AIR MIXTURE.

Given: 1000 cfm of air at T = 90°F, W = 120 Gr/lb is mixed with 500 cfm of air at T = 75°F, W = 70 Gr/lb.

Find:
a. Temperature of mixture.
b. Specific humidity of mixture.

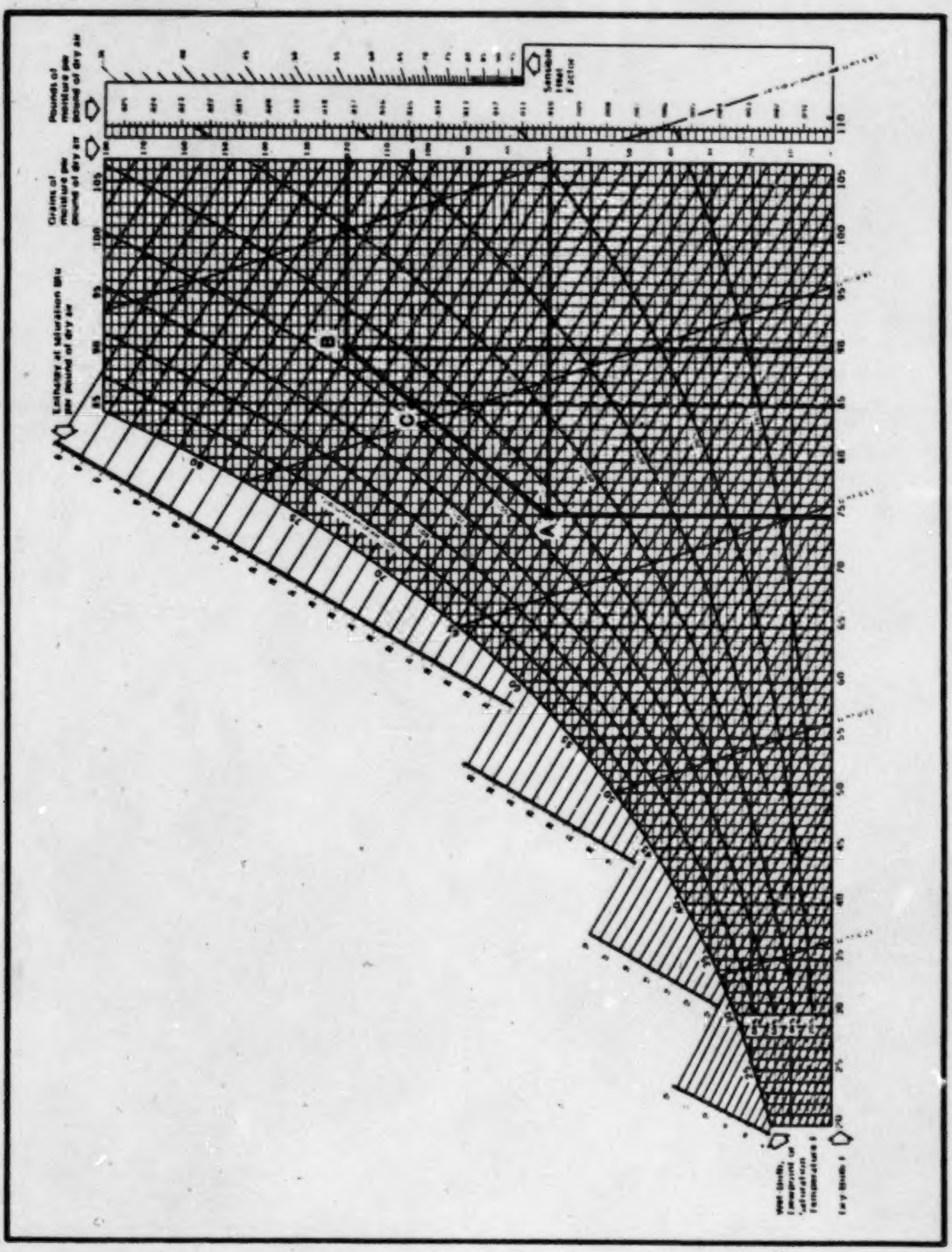
Solution:

a.
$$T_m = T_1 + \left(\frac{A_2}{A_1 + A_2}\right)(T_2 - T_1)$$
$$= 75°F = \left(\frac{1000\text{ cfm}}{1500\text{ cfm}}\right)(90°F - 75°F)$$
$$= 75°F + (0.67)(15°F)$$
$$T_m = 85°F$$

b.
$$W_m = W_1 + \left(\frac{A_2}{A_1 + A_2}\right)(W_2 - W_1)$$
$$= 70\text{ Gr/lb} + (0.67)(120\text{ Gr/lb} - 70\text{ Gr/lb})$$
$$= 70\text{ Gr/lb} + (0.67)(50\text{ Gr/lb})$$
$$W_m = 103.5\text{ Gr/lb}$$

Either of these values may be used to plot the point representing the mixture, as shown on the following graph.

Example B. Continued.



PLOTTING A PROCESS ON THE PSYCHROMETRIC CHART

Processes are examined using the psychrometric chart by plotting the initial and final conditions of the air and reading values from the chart. Many types of problems may be solved using the chart. One of the most useful applications of the chart is to determine correct operating temperature of the fan coil of an air conditioner. This is accomplished by the following method:

1. Plot the point representing the condition of the outside air.
2. Plot the point representing the condition of the return air. This is the same as the condition in the cooled space.
3. Connect these two points with a line. The condition of air entering the coil lies on this line.
4. Locate the point representing the condition of the air entering the coil using Equation 4 or 5. Plot this point.
5. Determine the sensible heat factor and draw a line from this value on the scale to the dot.
6. Draw a line parallel to Line 5, extending from Point 4 to the saturation line.
7. Locate the point where this line meets the saturation line. This is the apparatus dew point (ADP), the correct temperature for the fan coil.
8. The condition of the air leaving the coil is located on Line 6. Determine this point by using Equation 1 and the sensible heat load or Equation 2 and the latent heat load. Plot the point.

This completes the charting of the process. All other values may be read from the chart. This is illustrated in Example C.

EXAMPLE C: AN AIR CONDITIONING PROCESS.

Given: The following data for an air conditioning system:

Outside air: DB = 100°F
WB = 78°F

Room air: DB = 75°F
RH = 50%

Air supply: Ventilation = 300 cfm
Return = 2200 cfm
Supply (total) = 2500 cfm

Building load: Sensible: Q_S = 36,900 Btu/hr
Latent: Q_L = 6000 Btu/hr

Find: Apparatus dew point (ADP).
Temperature (DB) of air entering coil.
Temperature (DB) of air leaving coil.
Moisture content of air entering coil.
Moisture content of air leaving coil.
Enthalpy of air entering coil.
Enthalpy of air leaving coil.
Check solution by calculating total heat load by two methods:

a. Using change in enthalpy.
b. Using change in temperature and moisture content.

Solution: Two psychrometric charts are presented in the solution to this problem. The first illustrates the drawing of the process; the second illustrates the reading of data from the completed chart. Mathematical calculations of some quantites are included as checks and for illustrative purposes within the solution. These are not essential to solving the problem using the psychrometric chart, but they are advisable to insure accuracy.

Example C. Continued.

Note that heat load specifications are for the building only and do not include the conditioning of outside ventilation air. The outside air heat load and the totals will be determined in the solution.

a. Plot the condition of the outside air (Point 1) on the psychrometric chart.

b. Plot the condition of the room air (Point 2).

c. Determine change in water content of outside air from chart.

$$\Delta W = 109 \text{ Gr/lb} - 65 \text{ Gr/lb}$$

$$\Delta W = 44 \text{ Gr/lb.}$$

d. Determine latent heat load of outside air:

$$Q_L = (0.68)\ A\Delta W$$

$$= (0.68)(300 \text{ cfm})(44 \text{ Gr/lb})$$

$$Q_L = 8976 \text{ Btu/hr} \approx 9000 \text{ Btu/hr.}$$

e. Determine sensible heat load of outside air:

$$Q_s = (1.08)\ A\Delta T$$

$$= (1.08)(300 \text{ cfm})(100°\text{F} - 25°\text{F})$$

$$= (1.08)(300 \text{ cfm})(25°\text{F})$$

$$Q_s = 8100 \text{ Btu/hr.}$$

f. Calculate total heat loads:

	Building	Outside air	Total
Sensible	36,900	8,100	45,000 Btu/hr
Latent	6,000	9,000	15,000 Btu/hr
Total	42,900	17,100	60,000 Btu/hr

g. Calculate sensible heat factor:

$$Q_s/Q_T = \frac{45{,}000 \text{ Btu/hr}}{60{,}000 \text{ Btu/hr}}$$

$$Q_s/Q_T = 0.75$$

Example C. Continued.

h. Determine temperature of air entering coil:

$$T_E = T_R + (\frac{A_O}{A_T})(T_o - T_R)$$

$$= 75°F + (\frac{300\ cfm}{2500\ cfm})(100°F - 75°F)$$

$$= 75°F + (0.12)(25\ F°)$$

$$= 75°F + (3\ F°)$$

$$T_E = 78°F.$$

i. Determine temperature of air leaving coil:

$$\Delta T = \frac{Q_s\ (total)}{(1.08)(A_T O)}$$

$$= \frac{45,000\ Btu}{(1.08)(2500\ cfm)}$$

$$\Delta T = 16.7\ F°$$

$$T_L = T_E - \Delta T$$

$$= 78°F - 16.7\ F°$$

$$T_L = 61.3°F.$$

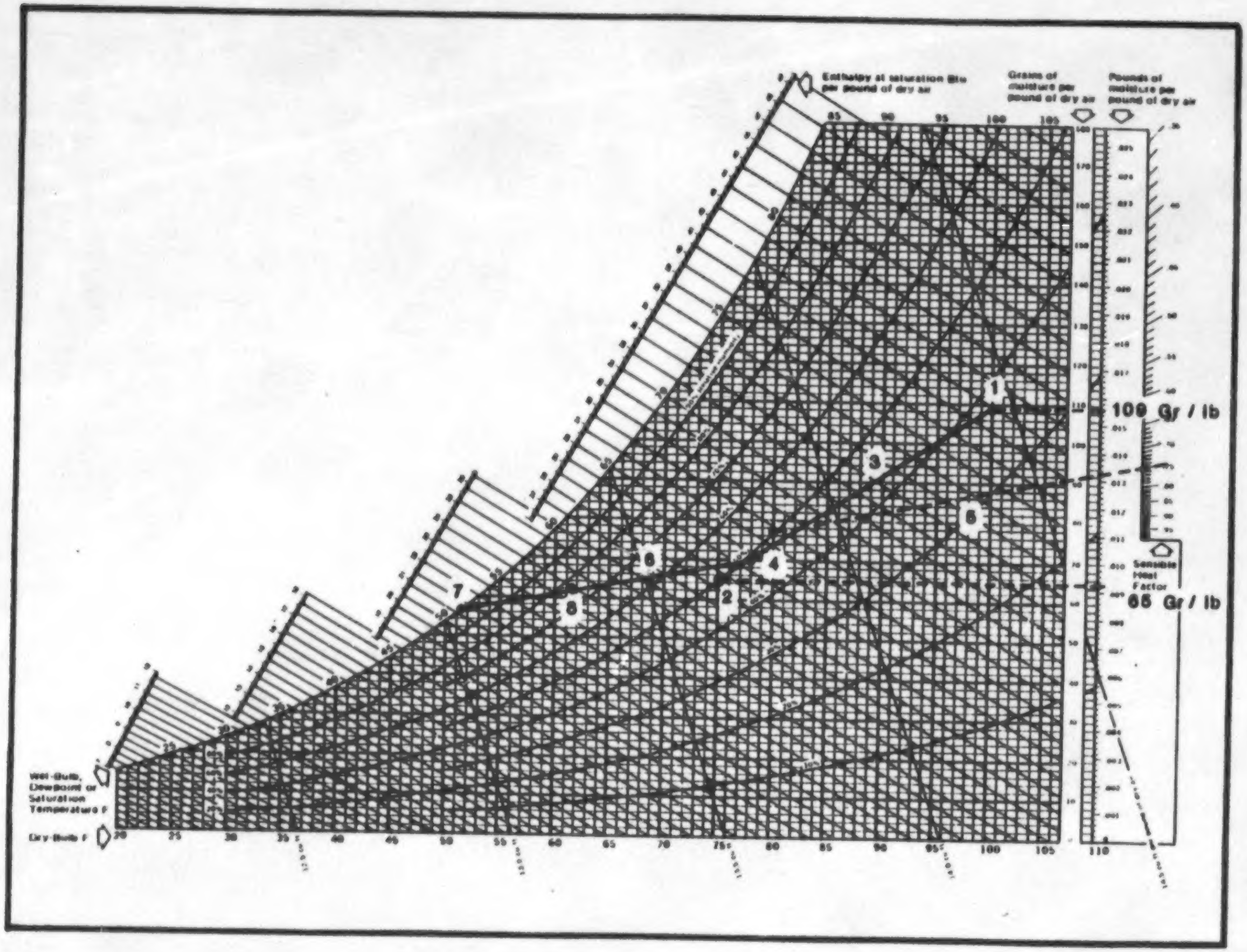
Note that a change in dry-bulb temperature of more than 20°F is unsuitable for comfort conditioning. If $\Delta T > 20$ F°, increase air flow rate.

At this point, all necessary data for the completion of the psychrometric chart have been determined.

j. Connect Points 1 and 2 with Line 3. The condition of the air entering the coil lies on this line.

k. Locate Point 4 where entering air temperature line crosses Line 3. This is the condition of the entering air. For mathematical verification, calculate water content of entering air as follows:

Example C. Continued.



Example C. Continued.

$$\Delta W = \frac{Q_L \text{ (outside air)}}{(0.68)\ A_T} \quad \text{(from Equation 2)}$$

$$= \frac{9000 \text{ Btu/hr}}{(0.68)(2500 \text{ cfm})}$$

$$\Delta W = 5.3 \text{ Gr/lb}$$

When outside air is mixed with return air, water content of the mixture is 5.3 Gr/lb greater than room air. The water content of air entering the coil is shown as follows:

$$W = 65 \text{ Gr/lb} + 5.3 \text{ Gr/lb}$$

$$W = 70.3 \text{ Gr/lb.}$$

This agrees with the value on the second chart.

l. Draw Line 5 from the sensible heat factor to the dot at 80°F, 50% RH.

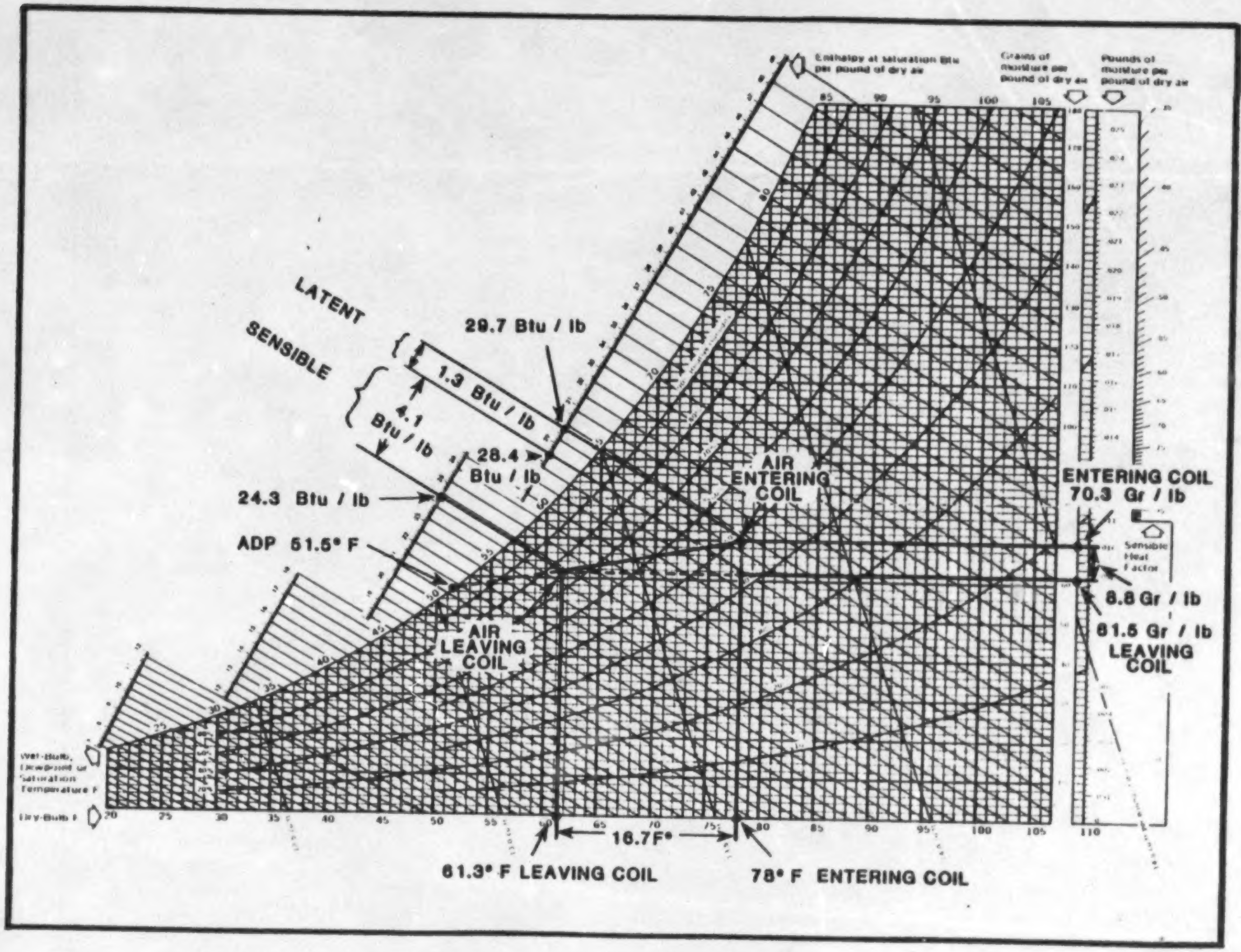
m. Draw Line 6 parallel to Line 5 from Point 4 to the saturation line. The condition of air leaving the coil lies on this line.

n. Locate the apparatus dew point at Point 7 on the saturation line. Note that an ADP of less than freezing will result in icing of the coil. If ADP < 32°F, increase air flow rate.

o. Locate Point 8 where the dry-bulb temperature of the air leaving the coil crosses Line 6. This is the condition of the air leaving the coil.

For mathematical verification, calculate water content of leaving air as follows:

Example C. Continued.



Example C. Continued.

$$\Delta W = \frac{Q_L \text{ (total)}}{(0.68)(AF_T)}$$

$$= \frac{15{,}000 \text{ Btu/lb}}{(0.68)(2500 \text{ cfm})}$$

$$\Delta W = 8.8 \text{ Gr/lb.}$$

The water content of the air leaving the coil is 8.8 Gr/lb less than that entering the coil.

$$W = 70.3 \text{ Gr/lb} - 8.8 \text{ Gr/lb}$$

$$W = 61.5 \text{ Gr/lb.}$$

This agrees with the value on the second chart.

p. Read specified values from the chart:

Apparatus dew point: ADP = 51.5°F

Temperature of air entering coil: T_E = 78°F

Temperature of air leaving coil: T_L = 61.3°F

Moisture content of air entering coil:

W_E = 70.3 Gr/lb

Moisture content of air leaving coil:

W_L = 61.5 Gr/lb

Enthalpy of air entering coil: H_E = 29.7 Btu/lb

Enthalpy of air leaving coil: H_L = 24.3 Btu/lb

Relative humidity and wet-bulb temperatures could also be determined from each point.

Check

a. $Q_T = (4.5)(A_T)(\Delta H)$

$$= (4.5)(2500 \text{ cfm})(29.7 \text{ Btu/lb} - 24.3 \text{ Btu/lb})$$

$$= (4.5)(2500 \text{ cfm})(5.4 \text{ Btu/lb})$$

$$Q_T = 60{,}750 \text{ Btu/hr.}$$

Example C. Continued.

This agrees closely with the specified total heat load.

b. $Q_s = (1.08)(A)(\Delta T)$

$= (1.08)(2500 \text{ cfm})(16.7 \text{ F}°)$

$Q_s = 45{,}090$ Btu/hr.

$Q_L = (0.68)(A)(\Delta W)$

$= (0.68)(2500 \text{ cfm})(8.8 \text{ Gr/lb})$

$Q_L = 14{,}960$ Btu/hr.

$Q_T = Q_s + Q_L$

$= 45{,}090 \text{ Btu/hr} + 14{,}960 \text{ Btu/hr}$

$Q_T = 60{,}050$ Btu/hr.

These values agree with specified values.

SUMMARY

The psychrometric chart contains information including dry-bulb temperature, wet-bulb temperature, specific humidity, relative humidity, and enthalpy of air. If any two of these quantities are known, the other can be read off the chart. Processes are represented by lines connecting the points representing the initial and final conditions of the air. The sensible heat, latent heat, and sensible heat factors are also included on the chart. One of the most important uses of the chart is to determine the apparatus dew point for an air conditioner fan coil.

EXERCISES

Students are required to furnish psychrometric charts.

1. Draw simple diagrams showing the following processes on the psychrometric chart:
   a. Comfort heating.
   b. Comfort air conditioning.
2. Complete the following table using the psychrometric chart.

Data Point	Dry-Bulb Temperature °F	Wet-Bulb Temperature °F	Specific Humidity %	Relative Humidity %	Enthalpy Btu/lb
1	70	57	____	____	____
2	____	____	____	70	35
3	____	____	30	40	____
4	95	____	120	____	____
5	85	____	____	____	26

3. A heating application requires an air flow rate of 3000 cfm and a temperature rise of 18 F°. Determine the sensible heat load.
4. An air conditioner has an air flow rate of 5000 cfm and a latent heat load of 30,000 Btu/hr. Determine the change in specific humidity of the air.
5. An air conditioner has a total heat load of 50,000 Btu/hr. The change in enthalpy is 3.0 Btu/lb. Determine the air flow rate.
6. The following two air streams are mixed. Determine the temperature and relative humidity of the result.
   a. 2000 cfm at a dry-bulb temperature of 52°F and specific humidity of 30 Gr/lb.

b. 1500 cfm at a wet-bulb temperature of 70°F and relative humidity of 55%.

7. Given the following data for an air conditioning system, determine the apparatus dew point.

Outside air temperature: DB = 95°F
WB = 74°F
Room condition: DB = 76°F
RH = 50%
Ventilation air: 1000 cfm
Return air: 2000 cfm
Sensible heat load (total): 42,000 Btu/hr
Latent heat load (total): 18,000 Btu/hr

8. Determine the condition of the air leaving the coil in the system above.

LABORATORY MATERIALS

Blank psychrometric charts.
Pencil.
Straight edge.
Calculator.

LABORATORY PROCEDURES

For the following problems, use the data and laboratory materials provided to complete the Data Table.

PROBLEM 1:

Outside air conditions: DB = 98°F
WB = 76°F

Room conditions: DB = 75°F

RH = 50%

Building sensible load: Q_S = 52,000 Btu/hr

Building latent load: Q_L = 9000 Btu/hr

Ventilation: A_V = 1000 cfm

Return air: A_R = 4000 cfm

PROBLEM 2:

Outside air conditions: DB = 100°F

WB = 80°F

Room conditions: DB = 40%

RH = 40%

Building latent load: Q_L = 22,000 Btu/hr

Building sensible load: Q_S = 52,000 Btu/hr

Ventilation: A_V = 500 cfm

Return air: A_R = 2000 cfm

PROBLEM 3:

Identify the system above that is unacceptable for comfort control. Recommend a change in system design to overcome this difficulty and solve the problem again.

DATA TABLE

DATA TABLE.

PROBLEM 1:

Temperature of air entering coil = ______________
Temperature of air leaving coil = ______________
Specific humidity of air entering coil = ________
Specific humidity of air leaving coil = _________
Enthalpy of air entering coil = ______________
Enthalpy of air leaving coil = _______________
Apparatus dew point = ___________________________

Is this an acceptable system for comfort air conditioning? Explain.

Data Table. Continued.

PROBLEM 2:

Temperature of air entering coil = ______________

Temperature of air leaving coil = _______________

Specific humidity of air entering coil = ________

Specific humidity of air leaving coil = _________

Enthalpy of air entering coil = _________________

Enthalpy of air leaving coil = __________________

Apparatus dew point = ___________________________

Is this an acceptable system for comfort air conditioning? Explain.

Data Table. Continued.

PROBLEM 3:

Temperature of air entering coil = ______________

Temperature of air leaving coil = ______________

Specific humidity of air entering coil = ________

Specific humidity of air leaving coil = _________

Enthalpy of air entering coil = ________________

Enthalpy of air leaving coil = _________________

Apparatus dew point = ___________________________

Is this an acceptable system for comfort air conditioning? Explain.

REFERENCES

Air Conditioning and Refrigeration Institute. Refrigeration and Air Conditioning. Englewood Cliffs, NJ: Prentice-Hall, Inc., 1979.

Althouse, Andrew D.; Turnquist, Carl H.; and Bracciano, Alfred F. Modern Refrigeration and Air Conditioning. Homewood, IL: The Goodheart-Willcox Company, Inc., 1979.

Honeywell Corporation. The Psychrometric Chart. 1977.

Most test questions require the use of psychrometric charts.

1. If the dry-bulb temperature is 82°F and the wet-bulb temperature is 62°F, the specific humidity is ...
   a. 55 Gr/lb.
   b. 0.0073 lb/lb.
   c. 27.8 Btu/lb.
   d. 31%.
2. 1000 cfm of air at a dry-bulb temperature of 100°F and a wet-bulb temperature of 75°F is mixed with 3000 cfm of air with a dry-bulb temperature of 76°F and a relative humidity of 50%. What is the temperature (DB) of the mixture?
   a. 87.5°F.
   b. 84°F.
   c. 94°F.
   d. 82°F.
3. What is the specific humidity of the mixture in Problem 2?
   a. 79 Gr/lb.
   b. 75 Gr/lb.
   c. 85 Gr/lb.
   d. 73 Gr/lb.
4. A heating system has input air of 60°F (DB) and 40% relative humidity. It supplies 2.8 Btu/lb, but adds no water vapor. What is the final temperature of the air?
   a. 62.8°F.
   b. 82°F.
   c. 46°F.
   d. 72°F.

5. 1000 cfm of air at a temperature (DB) of 50°F with a relative humidity of 40% is heated and humidified to 76°F and a relative humidity of 40%. The latent heat load is ...
   a. 21,760 Btu/hr.
   b. 28,080 Btu/hr.
   c. 49,840 Btu/hr.
   d. Zero.
6. The total heat load is 30,000 Btu/hr and the change in entropy is 5 Btu/lb. The air flow rate is ...
   a. 6000 cfm.
   b. 1333 cfm.
   c. 8824 cfm.
   d. 5555 cfm.
7. The air entering an air-conditioner coil has a dry-bulb temperature of 78°F and a moisture content of 70 Gr/lb. The sensible heat load is 80,000 Btu/hr and the latent heat load is 20,000 Btu/hr. The apparatus dew point is ...
   a. 51°F.
   b. 53°F.
   c. 55°F.
   d. 57°F.
8. The air flow rate in problem 7 is 4500 cfm. The specific humidity of the air leaving the coil is ...
   a. 63.5 Gr/lb.
   b. 61.5 Gr/lb.
   c. 65.6 Gr/lb.
   d. 68.5 Gr/lb.

9. An air conditioning system has the following specifications ...

Outside air: DB = 100°F
WB = 78°F

Room air: DB = 75°F
RH - 50%

Air supply: Ventilation = 500 cfm
Return air = 2000 cfm

Building load: Sensible: Q_s = 40,000 Btu/hr
Latent: Q_L = 5,000 Btu/hr.

The sensible heat factor is ...

a. 0.88.
b. 0.65.
c. 0.76.
d. 0.72.

10. The apparatus dew point in problem 9 is ...

a. 51°F.
b. 53°F.
c. 55°F.
d. 49°F.

11. The temperature of the air leaving the coil in problem 9 is ...

a. 60°F.
b. 62°F.
c. 64°F.
d. 66°F.